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Aviation Research Division  
Atlantic City International Airport  
New Jersey 08405

# **Small Unmanned Aircraft System for Pavement Inspection: Task 4—Execute the Field Demonstration Plan and Analyze the Collected Data**

November 2022

Final Report

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16. Abstract <p>The primary objectives of this research project are to develop recommended processes and procedures for using small unmanned/uncrewed aircraft system (sUAS) to complement current methods of airport Pavement Management Program (PMP) inspections and to evaluate various types of sUAS platforms and sensors that will lead to recommended minimum specifications required for consistently safe, reliable, and effective sUAS-assisted airport PMP inspections. Under Task 4, the research team developed and executed field demonstrated plans to safely deploy several sUAS at six airports in Michigan, Illinois, Iowa, and New Jersey from December 2020 to August 2021. Red, green, and blue (RGB) optical orthophotos, digital elevation models (DEMs), hillshades derived from DEMs, and thermal orthophotos collected using several sUAS at different altitudes were analyzed for their usefulness in airfield distress detection. Based on the data analyses and results, RGB orthophotos of 1.5 mm/pixel and DEMs of 6 mm/pixel resolution, or higher, are highly recommended for airfield pavement distress detection and rating.</p>					
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## LIST OF ABBREVIATIONS AND ACRONYMS

°C	Degrees Celsius
AAC	Asphalt overlay over asphalt concrete
AC	Asphalt cement concrete
AGL	Above ground level
APTech	Applied Pavement Technology, Inc.
ASR	Alkali-silica reaction
ASTM	American Society for Testing and Materials
BNW	Boone Municipal Airport
cm	Centimeter
DEM	Digital elevation model
DJI	Da-Jiang Innovations
FAA	Federal Aviation Administration
FBO	Fixed base operator
FLIR	Forward-looking infrared
FOG	Foot-on-ground
GCP	Ground control point
GIS	Geographic Information System
GPS	Global positioning system
ISU	Iowa State University
kg	Kilogram
km	Kilometer
kmph	Kilometers per hour
L&T	Longitudinal and transverse
lb	Pound
LTD	Longitudinal, transverse, and diagonal
m	Meter
M2EA	Mavic 2 Enterprise Advanced
mm	Millimeter
mm/pix	Millimeter per pixel
mp	Megapixel
MTO	Coles County Memorial Airport
MTRI	Michigan Tech Research Institute
N/A	Not applicable
ND	Not detected
NOTAM	Notice to Airmen
ONZ	Grosse Ile Municipal Airport
PCC	Portland cement concrete
PCI	Pavement condition index
PMP	Pavement Management Program
PRO	Perry Municipal Airport
RGB	Red-green-blue
RTK	Real-time kinematic
RW	Runway
SU	Sample unit

sUAS	Small unmanned/uncrewed aircraft system
sUAV	Small unmanned/uncrewed aircraft vehicle
TPOC	Technical point of contact
TTF	Custer Airport
TW	Taxiway
UAVSI	UAV Systems International
WWD	Cape May Airport

## EXECUTIVE SUMMARY

The primary objectives of this research project are to develop recommended processes and procedures for using small unmanned/uncrewed aircraft systems (sUASs) to complement current methods of airport Pavement Management Program (PMP) inspections and to evaluate various types of sUAS platforms and sensors that will lead to recommended minimum specifications required for consistently safe, reliable, and effective sUAS-assisted airport PMP inspections. Under Task 4, the research team developed and executed field demonstrated plans focusing on deploying several sUASs at six airports in Michigan, Illinois, Iowa, and New Jersey from December 2020 to August 2021. Red-green-blue (RGB) optical orthophotos, digital elevation models (DEMs), hillshades derived from DEMs, and thermal orthophotos collected using several sUASs at different altitudes were analyzed for their usefulness in airfield distress detection.

The results showed that RGB optical data are useful to detect as many as 13 Portland cement concrete (PCC) pavement distresses out of 14 available in this study and six out of nine asphalt concrete pavement distresses available on the test sites. Similarly, DEMs were useful for confirming the location of distresses with elevation change, such as faulting in PCC pavement and shoving in asphalt cement concrete pavement. The hillshades helped with visually interpreting elevation differences.

In addition, thermal orthophotos showed the potential to detect crack-based distresses. Based on the data analysis, the following minimum resolutions (in millimeters [mm]/pixel, shown as mm/pix) were recommended for airfield pavement distress detection and rating: RGB orthophotos of 5 mm/pix, DEMs of 20 mm/pix, and thermal orthophotos of 30 mm/pix or better (higher). However, RGB orthophotos of 1.5 mm/pix and DEMs of 6 mm/pix, or higher, are highly recommended for airfield pavement distress detection and rating.

## 1. INTRODUCTION

The primary objectives of this research project are to develop recommended processes and procedures for using small unmanned/uncrewed aircraft systems (sUASs) to complement current methods of airport Pavement Management Program (PMP) inspections and to evaluate various types of sUAS platforms and sensors that will lead to recommended minimum specifications required for consistently safe, reliable, and effective sUAS-assisted airport PMP inspections. sUAS are defined by the Federal Aviation Administration (FAA) as unmanned/uncrewed aircraft systems (UASs) smaller than 55 pounds (25 kilograms) (FAA, 2021a). Under Task 4, the detailed field demonstration plans developed for six airports were executed safely to collect imagery data with sUAS-based technologies and pavement inspection survey data conventionally. The collected data were post-processed and analyzed under this task. The detailed data collection procedures and analysis results are presented and discussed in this report in the following sections:

- Section 2. Field demonstration in Michigan
- Section 3. Field demonstration in Illinois
- Section 4. Field demonstration in Iowa
- Section 5. Field demonstration in New Jersey

## 2. FIELD DEMONSTRATION IN MICHIGAN

### 2.1 GROSSE ILE MUNICIPAL AIRPORT IN DECEMBER 2020

#### 2.1.1 Objectives

The research team executed the field demonstration plan developed for the sUAS data collection (Appendices A and B) at Grosse Ile Municipal Airport (ONZ), Grosse Ile Township, Michigan, on December 10 and 11, 2020. The field demonstration plan had the following objectives:

- Deploy and study the viability of the platforms and sensors that are available to the research team
- Evaluate the performance of available sUAS platforms and sensors for various distress visualization
- Study the effect of different flight altitudes and data resolution on distress identification
- Downselect the sensors and platforms recommended in task 2 to a smaller group

#### 2.1.2 Field Demonstration in December 2020

The data collection team traveled from Michigan Tech Research Institute (MTRI), Ann Arbor, Michigan, to the nearby ONZ airport (69 kilometers [km] away) to collect sUAS data from the target areas shown in Figure 1. The data collection team closely monitored the wind speed and temperature before conducting each sUAS flight. The temperature varied between 6 degrees

Celsius (°C) and 9 °C, and the wind speed ranged from 3 kilometers per hour (kmph) to 19 kmph. The safety plan developed by team for this data collection was also followed to ensure safe sUAS operation. Monitoring the air traffic during the flight operation visually and with aviation radios, yielding right of way to all other aircraft, driving with windows open while on airport property, operating at least 76.2 meters (m) away from the operational runways and taxiways, and minimizing the team’s presence on the runway and taxiway were some of the safety steps that were followed.



Figure 1. Focus Area for Data Collection with Six Selected Priority Sample Units Highlighted in Purple Circles

Two sUAS platforms were used for the data collection: (a) a Mavic 2 Pro with its integrated 20-megapixels (mp) RGB optical sensor with 13.2 × 8.8 mm size (Da-Jiang Innovations [DJI], 2020a) and (b) a Bergen Hexacopter (Bergen RC Helicopters, Vandalia, MI) that was used to

deploy a thermal forward-looking infrared (FLIR) Vue Pro R camera (FLIR, 2020), and a 45.7-mp Nikon D850 full-frame (35.9 × 23.9 mm sensor size) RGB optical digital camera with 50-mm prime lens. The Mavic 2 Pro with 20-mp sensor was used to collect sUAS data over Runway 17/35 and Taxiway A. The Nikon D850 and FLIR Vue Pro were used for higher resolution sample unit data collection. A total of 31 ground control points (GCPs) were placed throughout different parts of the pavement to enable accurate, sub-meter positioning of geospatial output products. This makes the comparison of geospatial data from different sources and time periods easier and more meaningful because data layers are more likely to align accurately. The details of the sUAS platforms, sensors, flight altitudes, and expected resolutions are shown in Table 1.

Table 1. Summary of sUAS Data Collection at ONZ in December 2020

Target Areas	sUAS Platforms	Sensor	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
RW1735 GI-10 SU 05, RW1735 GI-20 SU 05, RW1735 GI-20 SU 23, TWAHI-10 SU 15, TWAHI-10 SU 25	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	9.1	0.8	3
	Bergen Hexacopter	FLIR Vue Pro R	9.1	8.0	N/A
Taxiway A Section 10	Mavic 2 Pro	20-mp optical RGB	91.5	21	84
Runway 17/35	Mavic 2 Pro	20-mp optical RGB	91.5	21	84
			30.5	7.2	29.1

RW1735 GI-10 = Runway 17/35 Section 10

RW1735 GI-20 = Runway 17/35 Section 20

TWAHI-10 = Taxiway A Section 10

SU = Sample unit

AGL = Above ground level

DEM = Digital elevation model

N/A = Not applicable

A separate plan was developed for pavement condition index (PCI) survey data collection from airports in Michigan. A two-person crew from Applied Pavement Technology, Inc. (APTech) traveled to ONZ and conducted an airfield pavement distress foot-on-ground (FOG) survey following the American Society for Testing and Materials (ASTM) D5340-20 standard (ASTM, 2020). On January 19 and 20, 2021, the team located, identified, and recorded pavement distresses for 20 sample units onto their handheld Global Positioning System (GPS)-enabled field data collection tool. The data were processed, and the PCI values for all sample units and branches of the airfield pavement were calculated based on the ASTM D5340-20 standard. Because of overnight snowfall, the taxiway could not be inspected, and only data from the runway were collected. The PCI values for the different PCC pavement sections ranged from 3 to 50. A survey report was generated, which included sample unit information, the types of distresses present on the sample unit, and the PCI for each sample unit. The survey report was shared with other team members and the FAA.

## 2.2 GROSSE ILE MUNICIPAL AIRPORT IN MAY 2021

### 2.2.1 Objectives

The research team visited ONZ again on May 14, 2021, to collect data from Runway 17/35 and Taxiway A. The field demonstration had the following objectives:

- Perform full data collection using Mavic 2 Enterprise Advanced (M2EA)
- Evaluate the performance of the thermal data collected using M2EA
- Compare the FOG team's PCI value from the APTech manual survey with PCI values calculated from the pavement distresses identified in RGB optical data of M2EA
- Determine the minimum number of crews required for successful sUAS data collection from an airport

### 2.2.2 Field Demonstration in May 2021

The second field demonstration plan developed for ONZ was executed on May 14, 2021. The data collection team consisted of three members who traveled from Ames, Iowa, and Ann Arbor, Michigan, to ONZ and collected sUAS data by following all the standard safety protocols as recorded in the data collection safety plan. This data collection also evaluated the possibility of complete sUAS data collection with a single sUAS system. Two M2EA sUASs were deployed for both optical RGB and stereo thermal data collection (DJI, 2021). The complete data of Runway 17/35 and Taxiway A was collected with the M2EA's 48-mp Quad Bayer camera at 15.2-m altitude. A Quad Bayer camera enables a lower-resolution sensor (in this case, a 12-mp camera) to create images that are rated at higher resolution by placing more pixels behind a color filter; however, the underlying resolution is still the original (12 mp) resolution. This technology was first used in mobile phone cameras and was recently used in several DJI drones (GSMarena, 2019). Stereo thermal data were also collected from a selected sample unit using the same M2EA sUAS system at an altitude of 24.4 m. The M2EA has a dedicated thermally focused flight mode that enables the stereo overlapping thermal images to be collected with its thermal camera, which has a narrower field of view than the RGB camera. Ten AeroPoints™ were used as the only GCPs in this data collection, as shown in Figure 2. The details of the collected data and their resolutions are provided in Table 2. The research team followed the standard safety protocols as outlined in the sUAS data collection and safety plan provided in Appendices C and D.



Figure 2. Recommended Locations for GCPs at ONZ

Table 2. Summary of sUAS Data Collection at ONZ in May 2021

Target Areas	sUAS Platforms	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
Runway 17/35 and Taxiway A Section 10	M2EA	48-mp optical RGB Quad Bayer	15.2	*2.5	10
Runway 17/35 Section 10 sample unit	M2EA	640x512 pixel Stereo thermal	24.4	31.5	N/A

AGL = Above ground level

DEM = Digital elevation model

N/A = Not applicable

M2EA = Mavic 2 Enterprise Advanced

\*2.5 mm/pix is not true resolution due to being derived from the M2EA 48-mp Quad Bayer camera (see [https://www.gsmarena.com/quad\\_bayer\\_sensors\\_explained-news-37459.php](https://www.gsmarena.com/quad_bayer_sensors_explained-news-37459.php)).

The temperature and wind speeds were observed closely before deploying each flight, and they varied from 17 °C to 21 °C and 8 kmph to 24 kmph, respectively. Wind speeds and wind gusts of up to 24 kmph were considered to be safe for larger sUAS operations (in this case, the Bergen Hexacopter) and up to 40 kmph for the smaller sUASs (M2EA and Mavic 2 Pro).

The data collected in May 2021 was a full data collection with a single sUAS platform. The RGB optical data collected with M2EA at 15.2 m were processed with Agisoft Metashape using the location data of the 10 AeroPoints, which are rated to have approximately 3 centimeters (cm) positional accuracy or better. Even though the RGB data were collected from Taxiway A, the dataset was not further analyzed because the PCI survey team could not collect the data from the Taxiway because of snowfall. RGB optical orthophoto and DEM were created for Runway 17/35 and exported to a local drive for further analysis. The resultant orthophoto and DEM had a resolution of 2.5 mm/pix and 10 mm/pix, respectively. A hillshade was generated using the DEM for further data analysis. The complete orthophoto of Runway 17/35 was imported into ArcGIS Pro and visually analyzed for each distress identification and rating of the severity level. The noted airfield pavement distresses were used to calculate the PCI value based on the methods outlined in the ASTM D5340-20 standard (ASTM, 2020). The sUAS PCI values were then compared against the FOG survey PCI values.

## 2.3 RESULTS AND DISCUSSIONS OF GROSSE ILE MUNICIPAL AIRPORT DATA ANALYSIS

### 2.3.1 December 2020 Data Analysis

During the first data collection of ONZ, the research team collected optical imagery at three different altitudes using two different optical sensors and thermal imagery. The flights at multiple altitudes were designed to assess the data quality collected at different altitudes with different amounts of time.

Each collected photogrammetric stereo overlapping image dataset of the complete Runway 17/35 and complete Taxiway A dataset were imported separately into Agisoft Metashape for processing (Agisoft LLC, St. Petersburg, Russia). The locations of the sUAS imagery collected in December 2020 were corrected using the GCP's location, recorded with a Trimble GeoExplorer 6000 GPS (Trimble Inc., Sunnyvale, California, U.S.) units, and rated at approximately 10 cm or better positional accuracy. The images were processed on a high-end desktop workstation to create RGB optical orthophotos, DEMs, and a stereo thermal orthophoto. DEM is a raster image with each pixel representing the elevation. DEM was generated based on the dense cloud created in Agisoft Metashape. The resolution of the DEM depended on the resolution of the image captured by the optical RGB sensor. Each DEM was imported to ArcGIS Pro to produce a "hillshade DEM" for easier visualization and interpretation of elevation models (ESRI, West Redlands, CA, USA). As described by ESRI, a hillshade is derived from the DEM and "produces a grayscale 3D representation of the terrain surface, with the sun's relative position taken into account for shading the image" (ESRI, 2021a).

Mavic 2 Pro at 91.5 m altitude provided optical RGB orthophoto of 21 mm/pix and DEM of 84 mm/pix. The data collection was fast, but the DEM was too coarse to identify any distresses. In addition, the 21-mm/pix orthophotos were only useful to detect high-severity durability cracking, shattered slab, corner breaks, and large patching. By flying the Mavic 2 Pro at a lower altitude of 30.5 m, the resulting orthoimage resolution increased to 7.2 mm/pix, which allowed for the identification of smaller defects, such as cracks with lower severity, as shown in figures below. The resulting DEM, having a resolution of 29 mm/pix, improved from flying at lower altitudes but still could only be used to identify larger defects. Examples of detectable distresses at a flight altitude of 30.5 m using the DJI Mavic 2 Pro include high-severity larger patches and durability cracks. Detailed comparisons are made with the May 2021 data collection, as shown in Figure 3 through Figure 15.

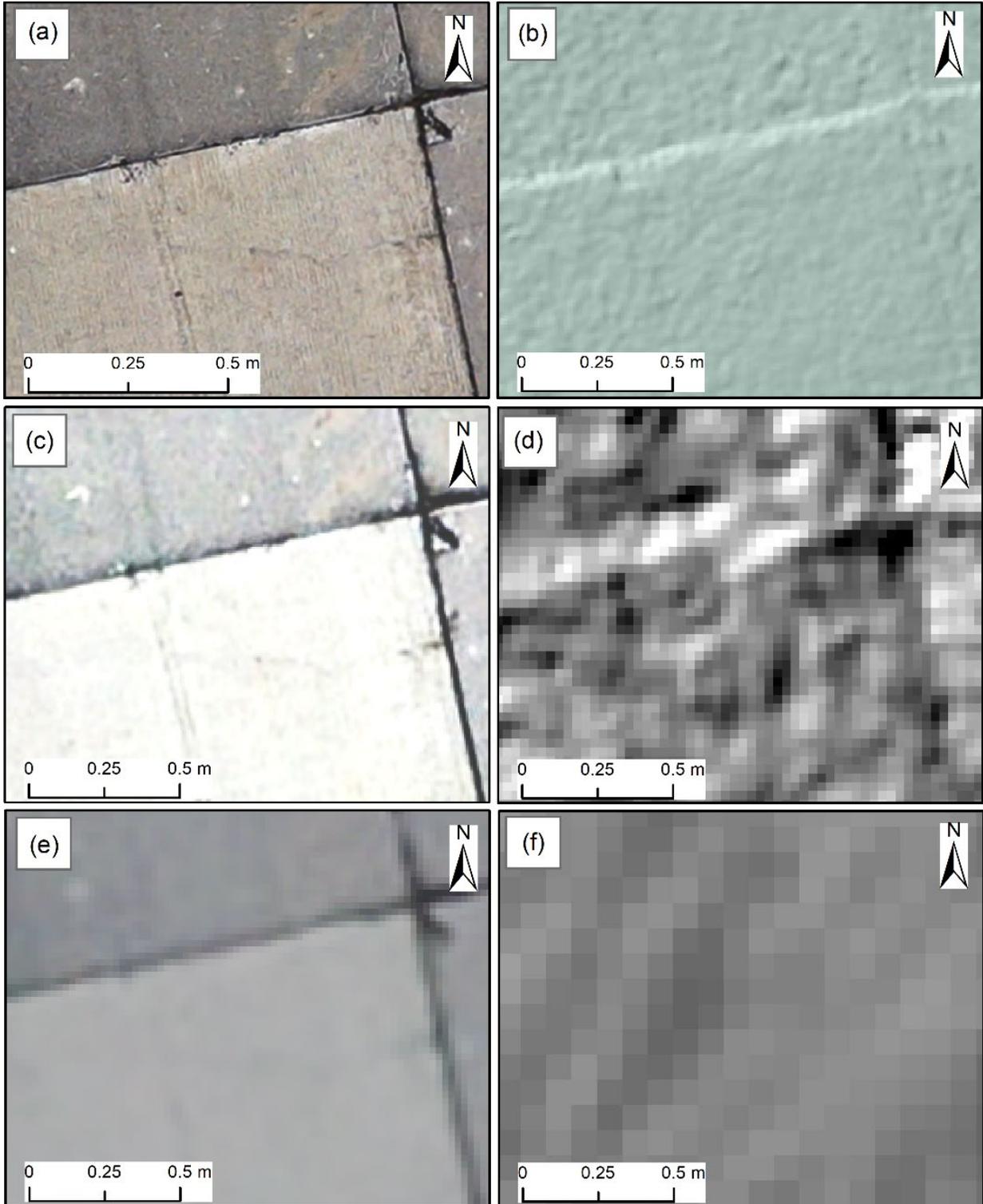


Figure 3. Low-severity Corner Break and Medium-severity Faulting in (a) 2.5-mm/pix Orthophoto, (b) 10-mm/pix DEM, (c) 7.2-mm/pix Orthophoto, (d) 29.1-mm/pix DEM, (e) 21-mm/pix Orthophoto, and (f) 84-mm/pix DEM

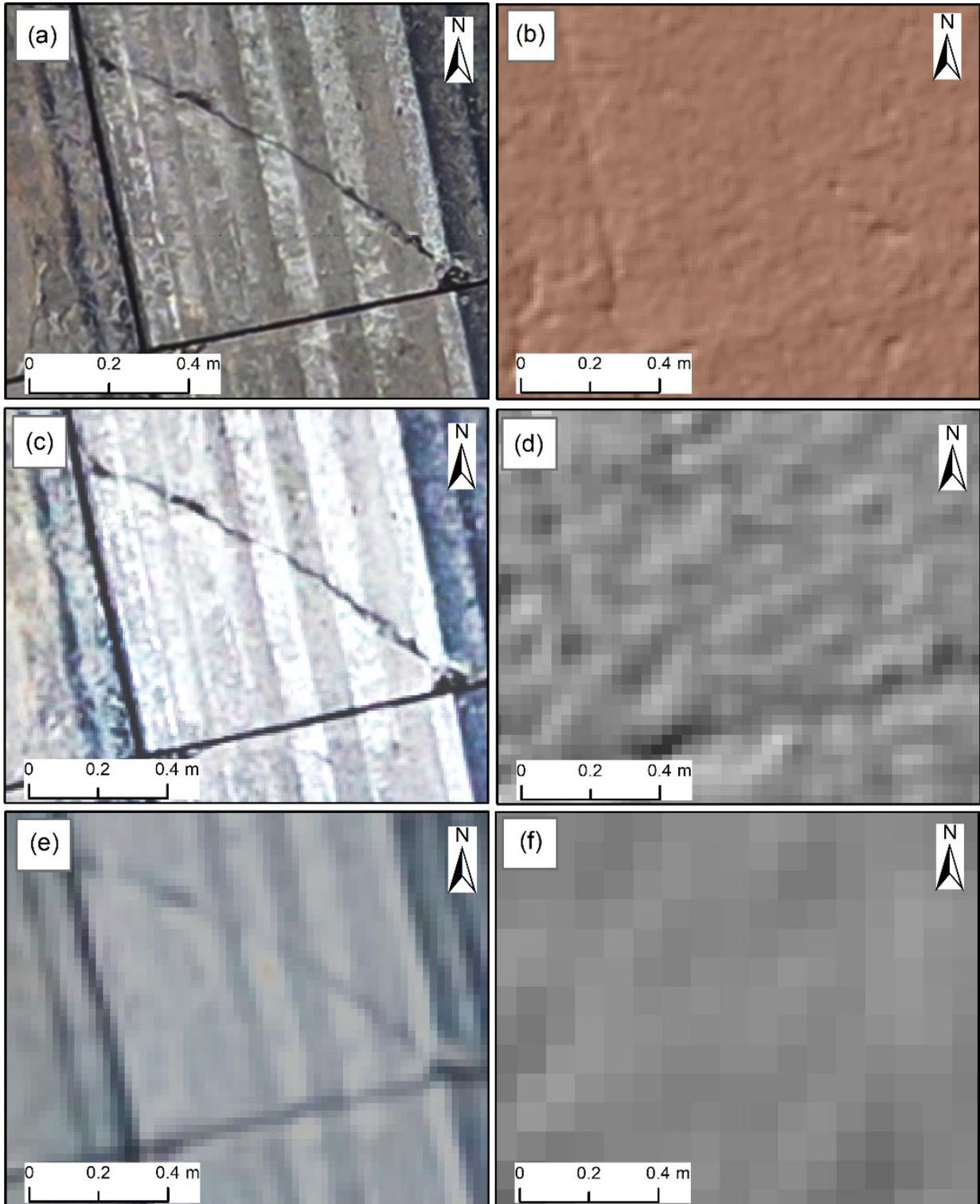


Figure 4. Medium-severity Corner Break in (a) 2.5-mm/pix Orthophoto, (b) 10-mm/pix DEM, (c) 7.2-mm/pix Orthophoto, (d) 29.1-mm/pix DEM, (e) 21-mm/pix Orthophoto, and (f) 84-mm/pix DEM

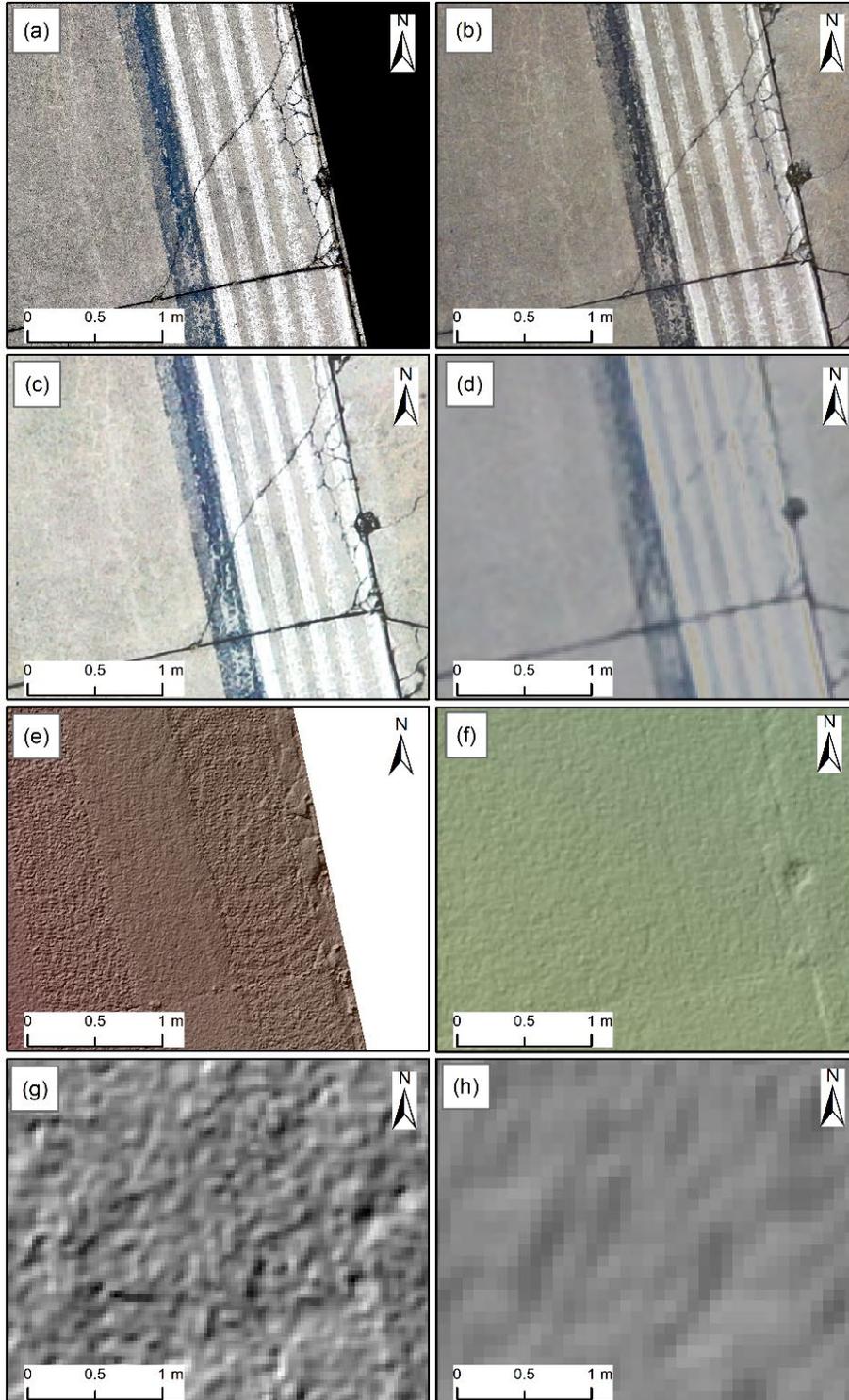


Figure 5. High-severity Corner Break in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

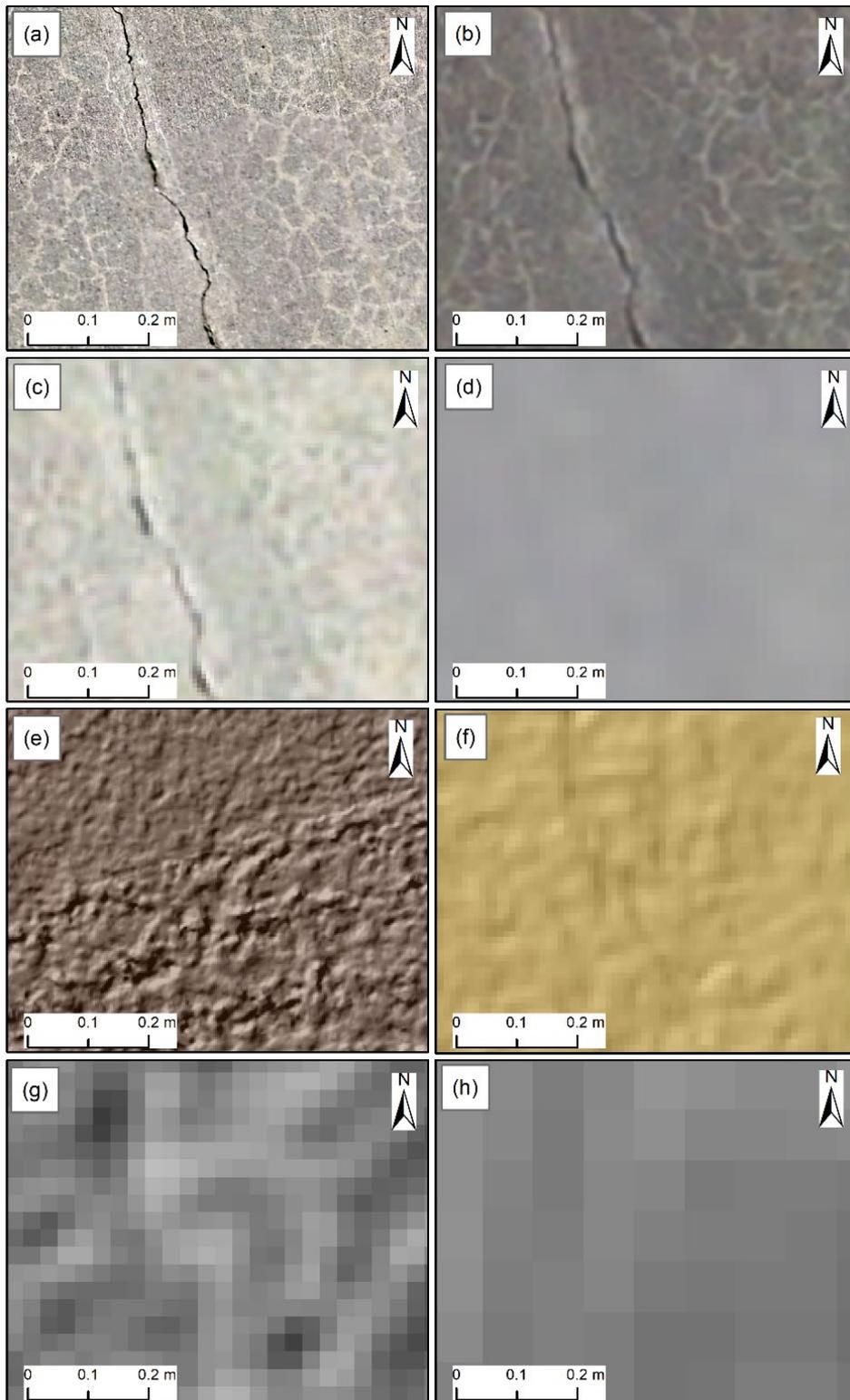


Figure 6. Low-severity LTD Cracking in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

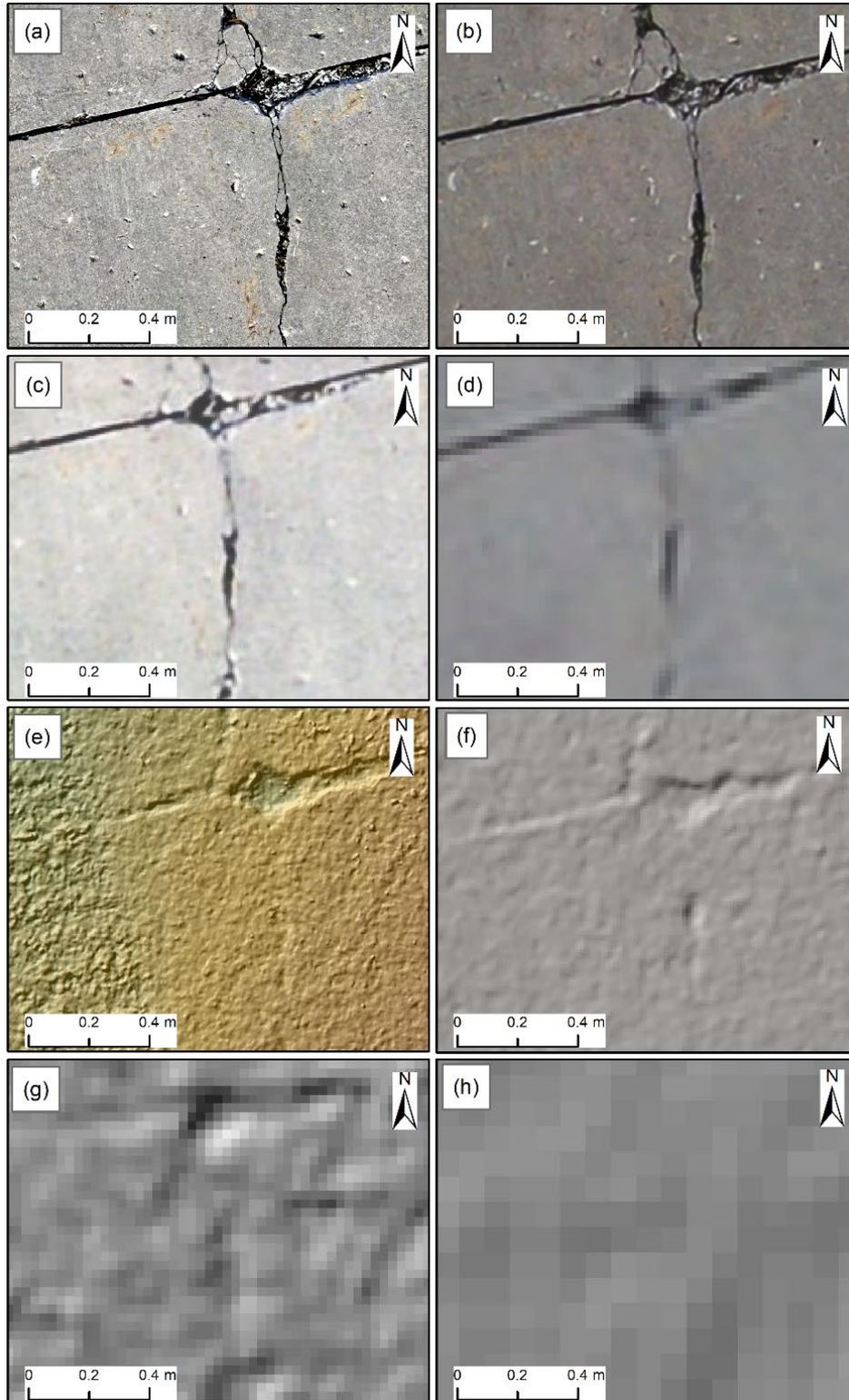


Figure 7. Medium-severity LTD Cracks and D-Cracking (M) in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

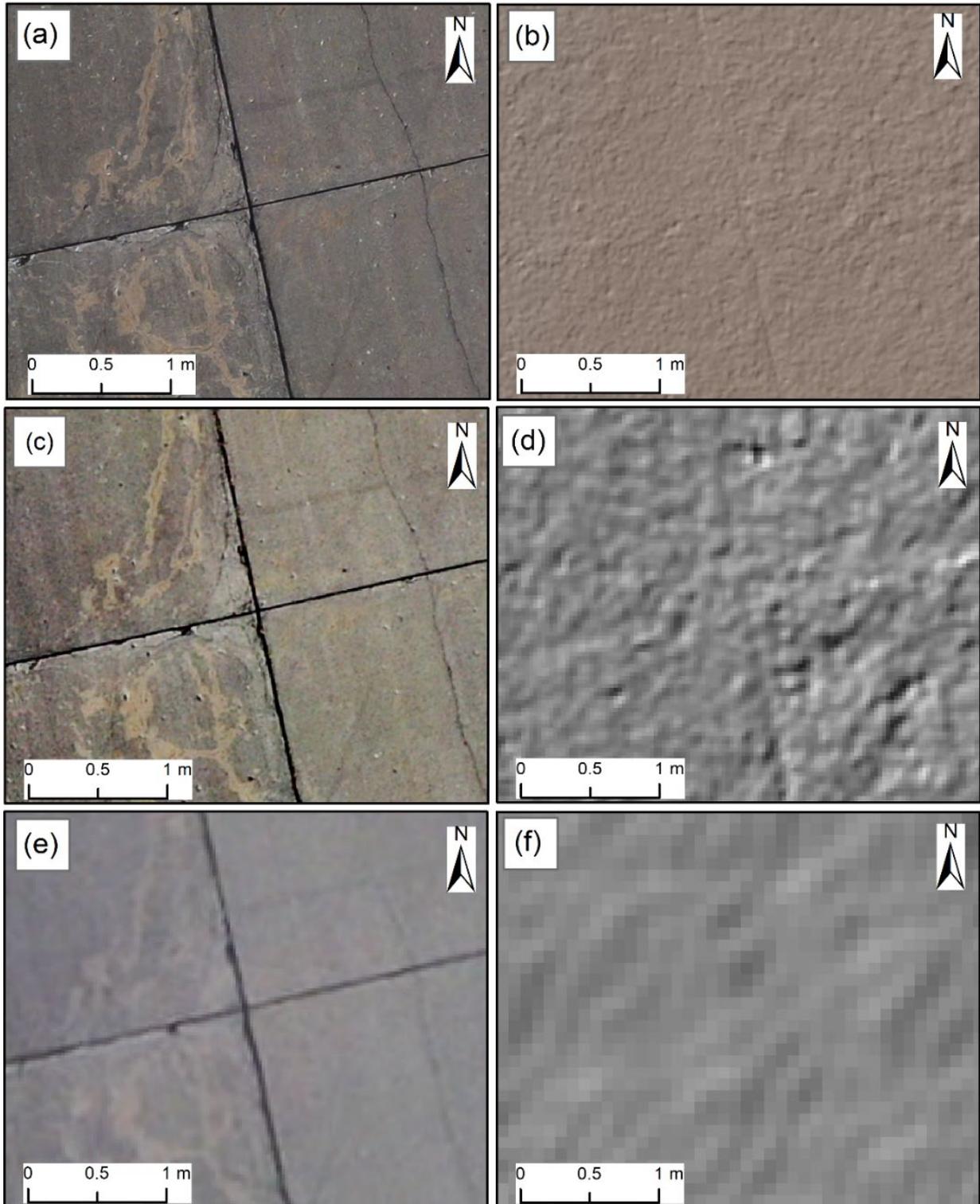


Figure 8. Low-severity D-Cracking, Low-severity ASR, and Medium-severity ASR in (a) 2.5-mm/pix Orthophoto, (b) 10-mm/pix DEM, (c) 7.2-mm/pix Orthophoto, (d) 29.1-mm/pix DEM, (e) 21-mm/pix Orthophoto, and (f) 84-mm/pix DEM

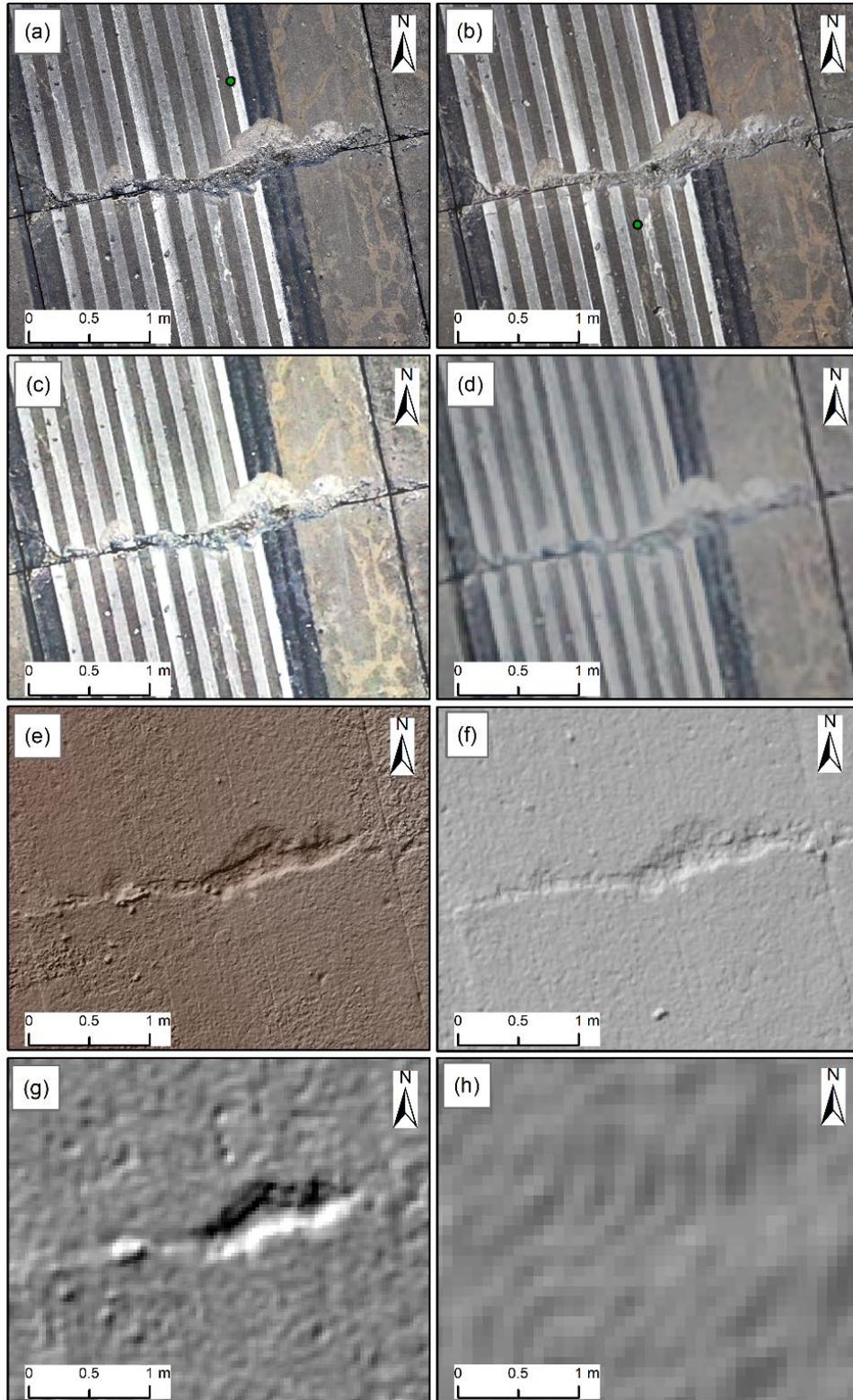


Figure 9. High-severity D-Cracking in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

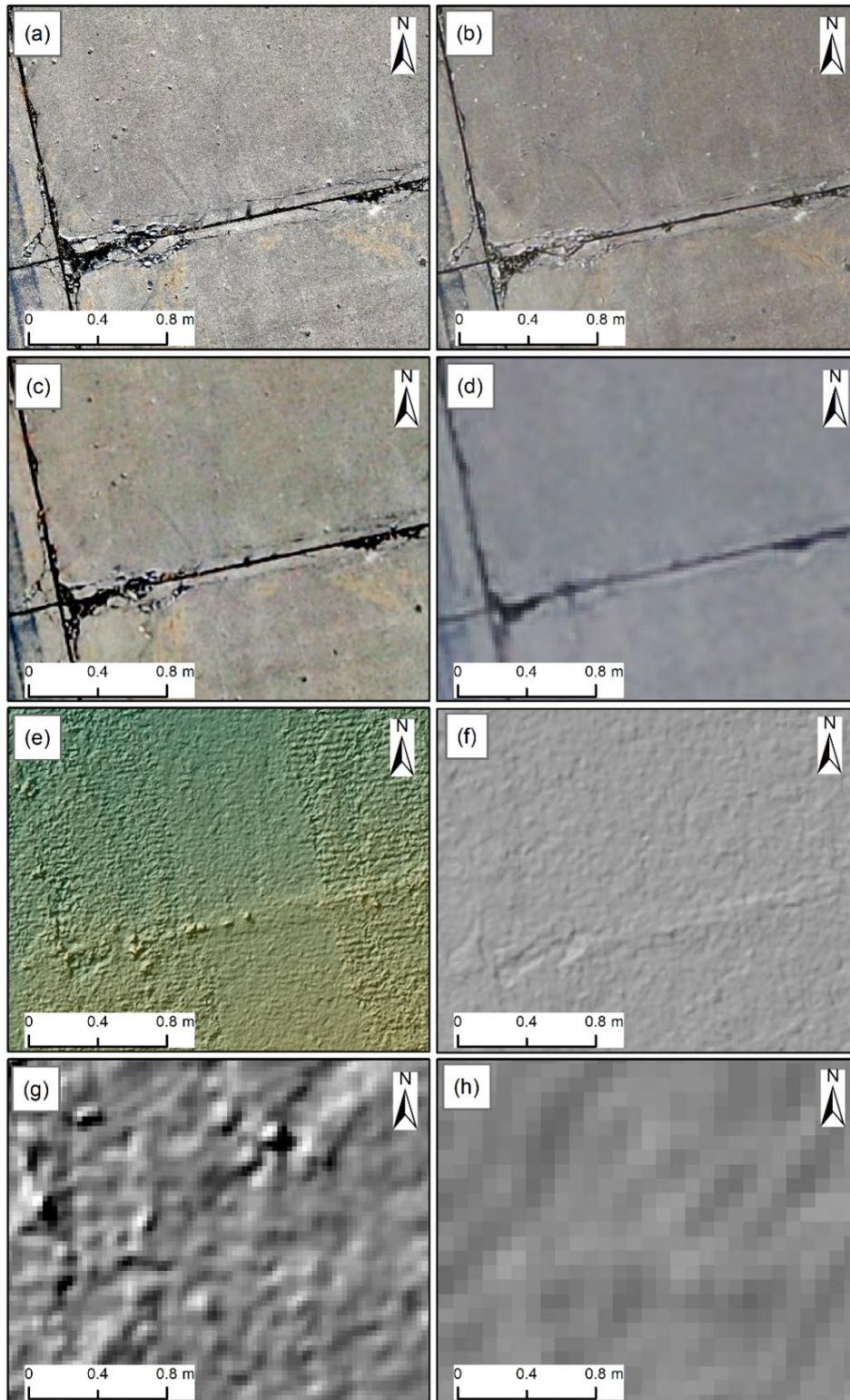


Figure 10. High-severity Joint Seal Damage in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

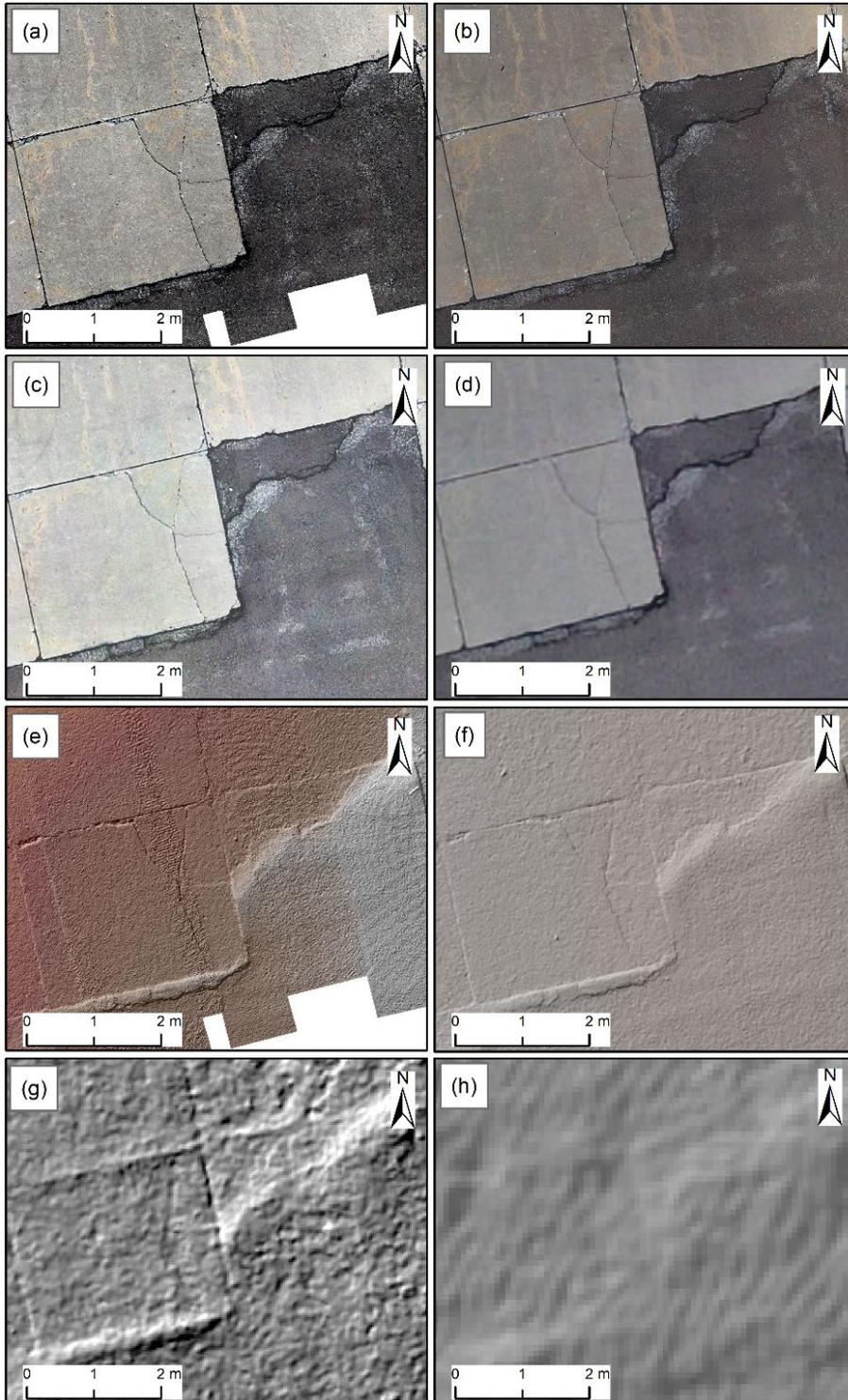


Figure 11. Medium-severity Shattered Slab, High-severity Large Patch , and Low-severity ASR in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

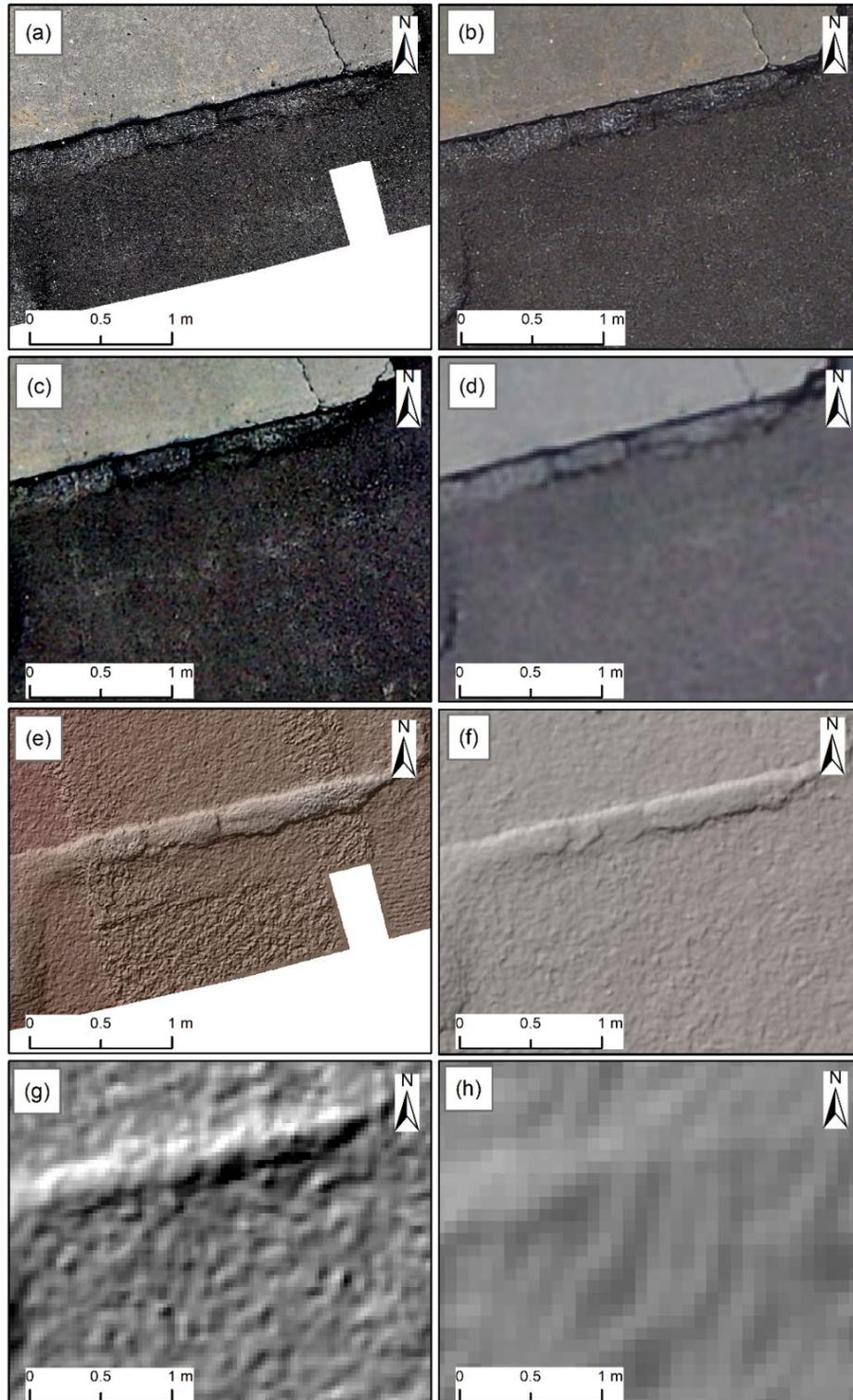


Figure 12. Medium-severity Large Patching in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

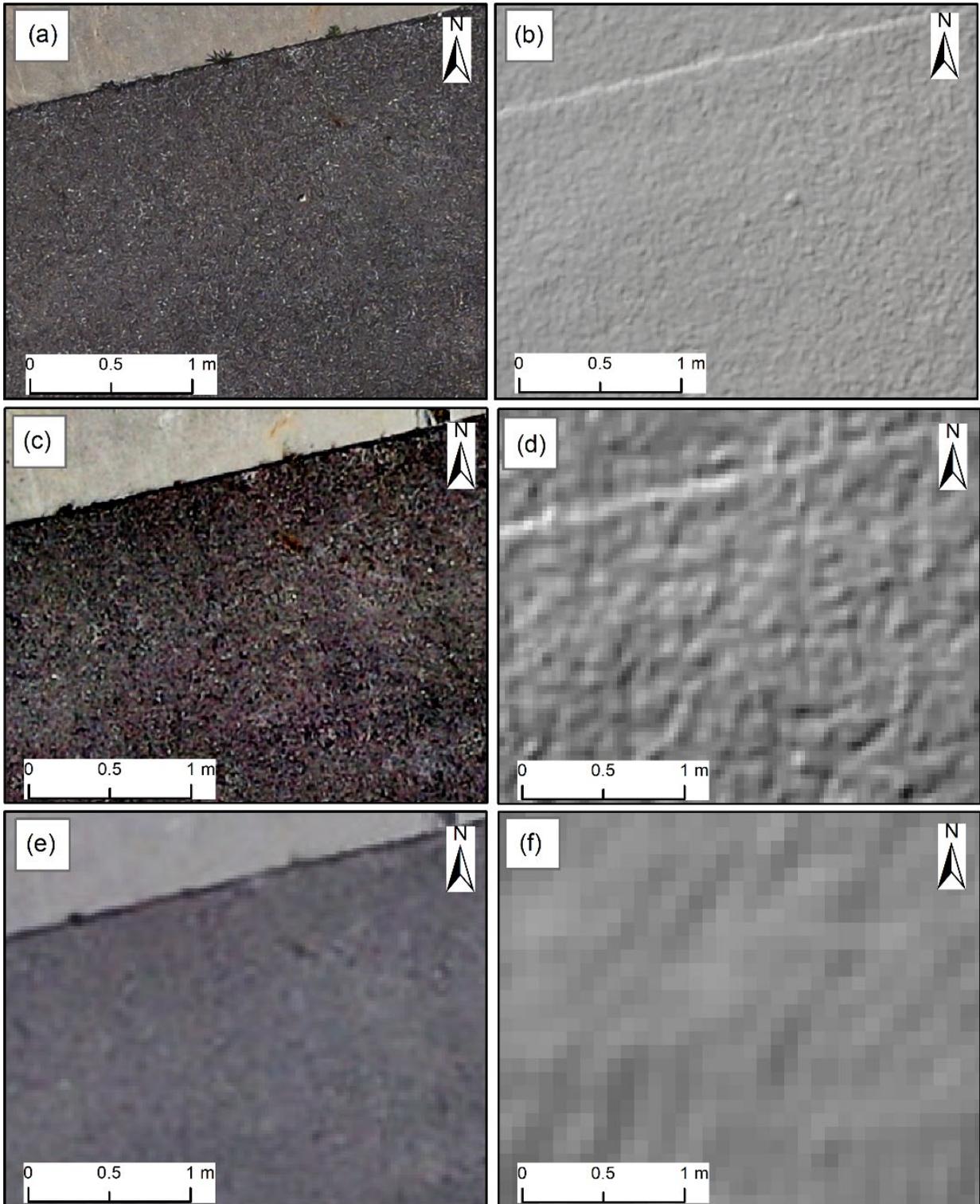


Figure 13. Low-severity Large Patching and High-severity Joint Seal Damage in (a) 2.5-mm/pix Orthophoto, (b) 10-mm/pix DEM, (c) 7.2-mm/pix Orthophoto, (d) 29.1-mm/pix DEM, (e) 21-mm/pix Orthophoto, and (f) 84-mm/pix DEM

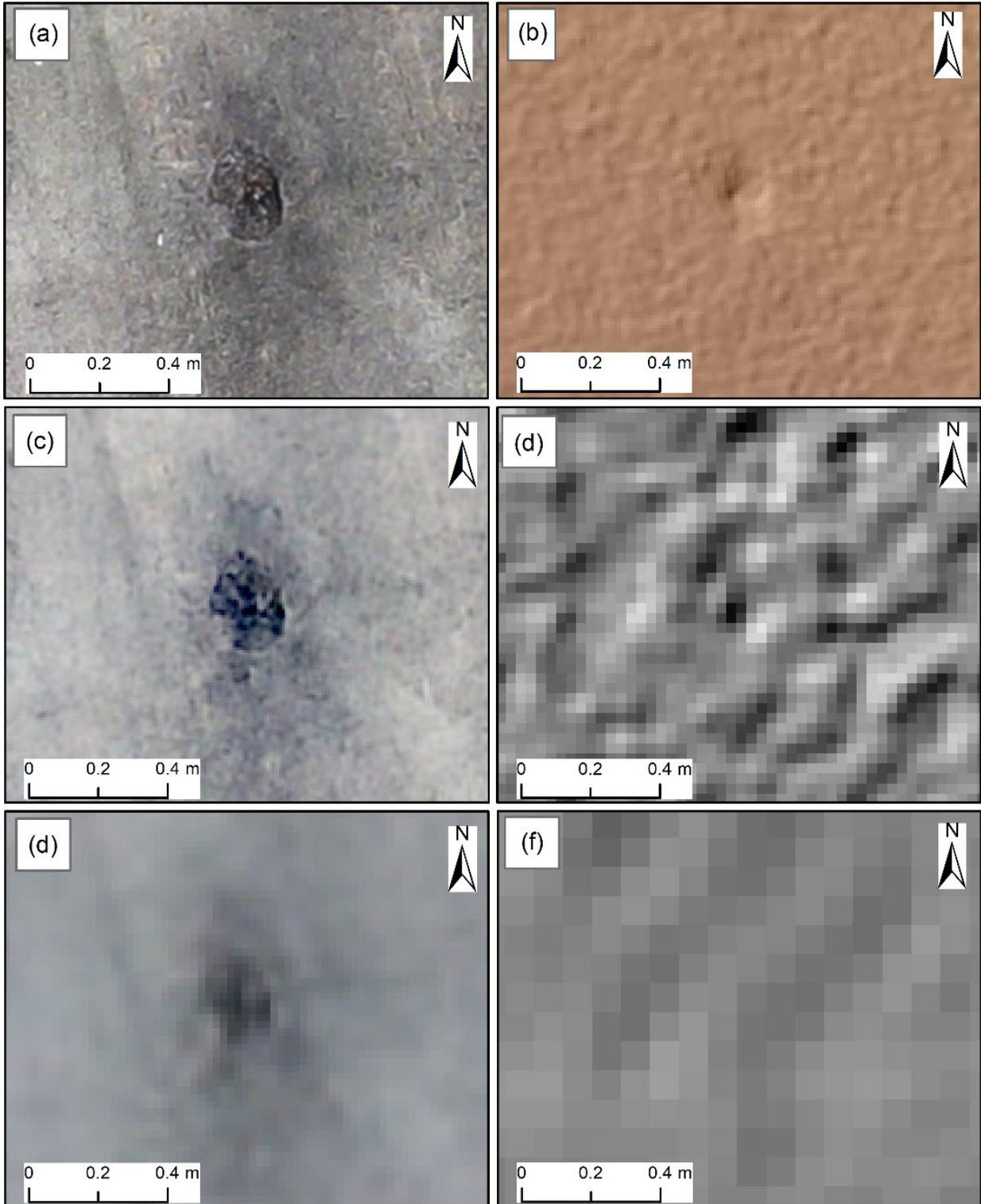


Figure 14. Medium-severity Scaling in (a) 2.5-mm/pix Orthophoto, (b) 10-mm/pix DEM, (c) 7.2-mm/pix Orthophoto, (d) 29.1-mm/pix DEM, (e) 21-mm/pix Orthophoto, and (f) 84-mm/pix DEM

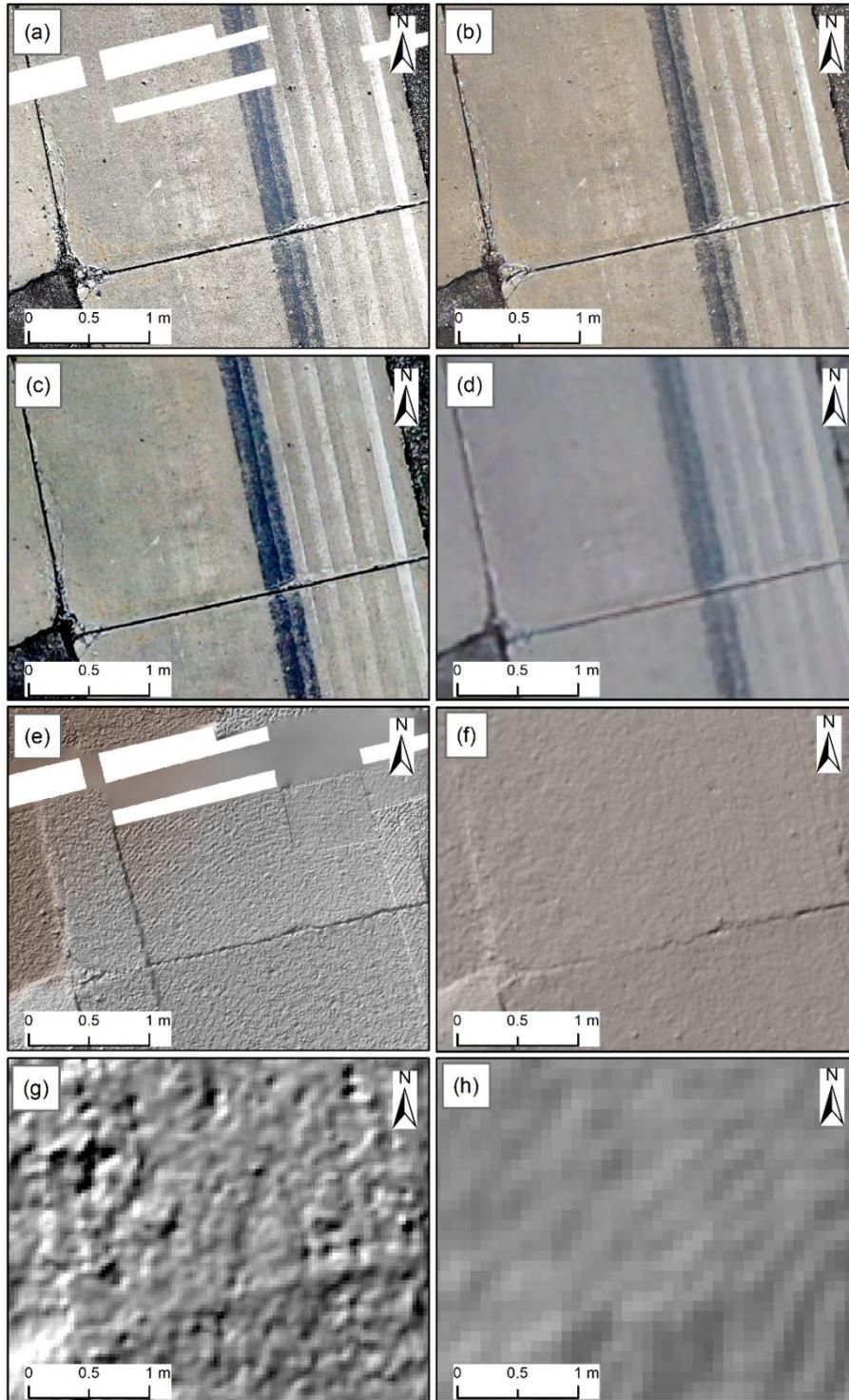


Figure 15. Medium-severity Faulting, Medium-severity D-Cracking in (a) 0.8-mm/pix Orthophoto, (b) 2.5-mm/pix Orthophoto, (c) 7.2-mm/pix Orthophoto, (d) 21-mm/pix Orthophoto, (e) 3-mm/pix DEM, (f) 10-mm/pix DEM, (g) 29.1-mm/pix DEM, and (h) 84-mm/pix DEM

The Bergen Hexacopter flights with the 45.7-mp Nikon D850 flown at 9.1 m produced the highest resolution survey at ONZ. Orthomosaic resolution was produced at 0.8 mm/pix, which allows for the identification of minor cracks (Figure 3 and Figure 6). To collect imagery over a single sample unit of approximately 210 m<sup>2</sup> required approximately 2.5 minutes of flight time. The primary disadvantage of the data collected by the Bergen Hexacopter with Nikon D850 at 9.1 m was that it would likely require too much time to complete an entire runway survey at this altitude, which may not be practical for airport pavement inspection, at least with this older sUAS system. Thermal imagery would take a similar amount of time with the separate sensor tested at ONZ (a FLIR Vue Pro R 640x512 30-hz system). This time estimate does not include the time required for landing, changing the batteries, and takeoff after every 16 minutes of flight time. Processing times for this anticipated high-resolution dataset would also be significantly more than the lower-resolution Mavic 2 Pro data. A single sample unit required approximately 150 images to be fully covered and took about an hour to process using 3D photogrammetry software, such as Agisoft Metashape and advanced computational capabilities of a multi-core processing workstation. The research team has estimated that it would require at least 9,000 images to cover Runway 17/35 at a 9.1 m flight altitude, and processing time for such a dataset could be several days or even up to a week. Therefore, the same platform flown at 18.3 m is recommended for a reasonable compromise between high-resolution outputs and data collection time.

The initial findings after the first field demonstration at ONZ are summarized as follows:

- Images with a resolution of 21 mm/pix collected using the 20 mp DJI Mavic 2 Pro sensor flown at 91.5 m were too coarse to detect or rate most airport pavement distresses (Figure 3 to Figure 15).
- Images with a resolution of 7.2 mm/pix collected using the 20-mp DJI Mavic 2 sensor flown at 30.5 m appeared useful for detecting several airport pavement distresses. The detectable distresses (at least at one severity level) were: longitudinal, transverse, and diagonal (LTD) cracks, durability cracking, shattered slab, corner break, large patching, and small patching (Figure 5, Figure 7, Figure 9, Figure 11, Figure 12, and Figure 13). However, it was not always possible to accurately rate most of the identified distresses.
- Flights at 9.1 m height with the Nikon D850 45.7-mp sensor produce functional and very high-resolution optical images and DEM data, yet it was likely to be challenging to deploy in a time-efficient manner at airports.
- Thermal data appeared promising to detect at least some distresses, such as spalling, and help emphasize crack locations.

### 2.3.2 May 2021 Data Analysis

The ONZ data collected in December 2020 were compared with May 2021 data for complete data analysis. The PCI values estimated using the pavement distresses identified in the 2.5-mm/pix data were also compared with APTEch's manual FOG survey PCI values for evaluating the performance of sUAS in airfield pavement distress detection.

The following results are concluded from the field demonstration and analysis of data collected at ONZ in May.

- Images with a resolution of 2.5 mm/pix are adequate to identify all crack-based distresses at all severity levels. The crack-based distresses found at ONZ were: LTD cracks, D cracking, shattered slabs, and corner breaks (Figure 3 to Figure 9 and Figure 11).
- Identification of alkali-silica reaction (ASR) was challenging with the 2.5 mm/pix data, especially for low-severity ASR (Figure 8 and Figure 11).
- Faulting of 1 cm or less could not be detected with the 10-mm/pix DEM generated from processing the Mavic 2 Pro data. DEMs of 3 mm/pix were useful for suspected faulting with medium-severity detection (Figure 16).
- A three-member sUAS crew can successfully collect sUAS data at an airport with a lower number of air traffic without interrupting the general flow. The three-person team consists of a remote pilot in command, one visual observer, and one person responsible for managing the logistics and providing additional manual documentation of airfield distresses; these activities can include charging the sUAS batteries, taking location-tagged field photos, placing and removing ground control points, etc. It is also helpful for the crew to include an additional sUAS pilot with a dedicated observer to enable simultaneous data collection at two different airport locations. Each crew should have a dedicated aviation radio for efficient operations.

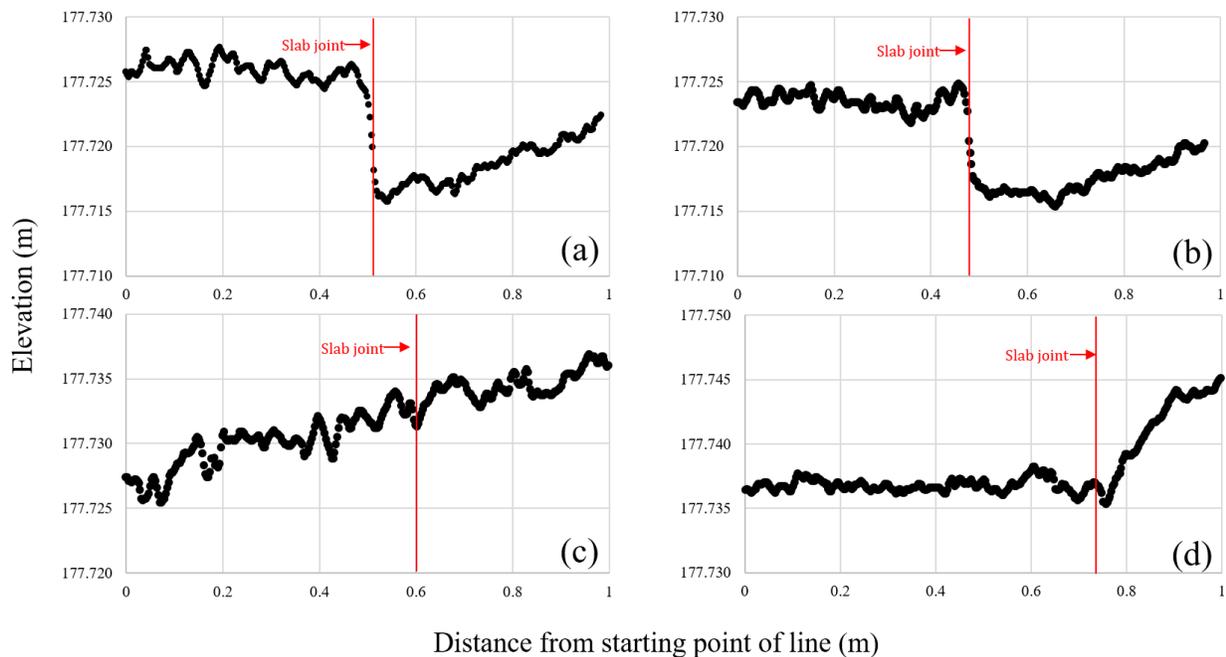


Figure 16. Medium-severity Faulting Detection in 3-mm/pix DEM (a, b) Slab Joint with Medium-severity Faulting Showing a 1-cm Sudden Drop in Elevation, and (c, d) Slab Joint Without Faulting that Does Not Show a Sudden Elevation Drop

All the data collected from ONZ in December 2020 and May 2021 were compared to identify individual distresses with different severity. The results are summarized in Table 3.

Table 3. Summary of the ONZ Findings

ASTM D5340 Distress	Severity	Resolution Tested (mm/pix)		Distress Detected in Maximum Resolution (mm/pix)		Remarks
		Orthophoto	DEM	Orthophoto	DEM	
Corner break (62)	L	*2.5, 7.2, 21	10, 29, 84	*2.5	ND	Figure 3
	M			21	ND	Figure 4
	H	0.8, *2.5, 7.2, 21	3, 10, 29, 84	21	ND	Figure 5
LTD cracks (63)	L	0.8, *2.5, 7.2, 21	3, 10, 29, 84	7.2	ND	Figure 6
	M			21	ND	Figure 7
Durability cracking (64)	L	*2.5, 7.2, 21	10, 29, 84	7.2	ND	Figure 8
	M	0.8, *2.5, 7.2, 21	3, 10, 29, 84	21	10	Figure 7
	H				29	Figure 9
Joint seal damage (65)	H	0.8, *2.5, 7.2, 21	3, 10, 29, 84	7.2	ND	Figure 10
Large patching (66)	L	*2.5, 7.2, 21	10, 29, 84	21	ND	Figure 13
	M	0.8, *2.5, 7.2, 21	3, 10, 29, 84	21	29	Figure 12
	H					Figure 11
Scaling (70)	M	*2.5, 7.2, 21	10, 29, 84	21	10	Figure 14
Faulting (71)	L	0.8, *2.5, 7.2, 21	3, 10, 29, 84	ND	ND	Figure 15
	M				3	Figure 3
Shattered slab (72)	M	0.8, *2.5, 7.2, 21	3, 10, 29, 84	21	10	Figure 11
ASR (76)	**L, M	0.8, *2.5, 7.2, 21	3, 10, 29, 84	7.2	ND	Figure 11 Figure 8

ASR = Alkali-silica reaction

DEM = Digital elevation model

ND = Not detected

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

\*\*Low-severity ASR detection not always possible

It was observed that the faulting was challenging to detect in optical RGB orthophoto, regardless of the resolution. Further analysis with a 3-mm/pix DEM proved to help confirm the location of the faulting through the slab joints. Several polylines were drawn in ArcGIS Pro perpendicular to the slab joint, which was suspected of having faulting. Multiple polylines were also drawn perpendicular to the slab joints with no faulting. The Stack Profile (3D Analyst) tool of ArcGIS Pro was used to calculate the pixel value of DEM through the lines (ESRI, 2021b). The output was a table containing the location of each pixel from the origin of the line and the pixel value, in this case elevation, in that particular point. Figure 16 (a) and Figure 16 (b) represent two different lines drawn perpendicular to the slab joint with medium severity faulting. The DEM showed a 1-cm elevation change where faulting was recorded. Figure 16(c) and Figure 16(d) represent two

additional lines drawn perpendicular to another slab joint without any faulting. As shown, the lines on Figure 16 (c) and Figure 16 (d) did not show a drastic change in the elevation. However, a similar analysis with 10 mm/pix DEM created using 2.5 mm/pix orthophoto collected with M2EA at 15.2 m did not clearly distinguish between slab joints with faulting and slab joints with no faulting.

Runway 17/35 had a total of 20 sample units where FOG PCI data were collected. The same sample units were visually observed to identify and rate possible pavement distresses. The distresses, severity, and affected slabs or sample units were considered to calculate the PCI value according to the guidelines outlined in ASTM D5340-20. The sUAS PCI and PCI values are plotted and shown in Figure 17. The sUAS PCI values were both higher and lower than the manual PCI. In some cases, low-severity ASR was not detected with the sUAS data, which is the main reason for higher sUAS PCI values compared to the FOG PCIs. Conversely, newly detected LTD cracks and high-severity durability cracking resulted in lower sUAS PCIs than the FOG PCI. The mean FOG PCI was 34.6, whereas the mean sUAS PCI was 32.9 for all the sample units.

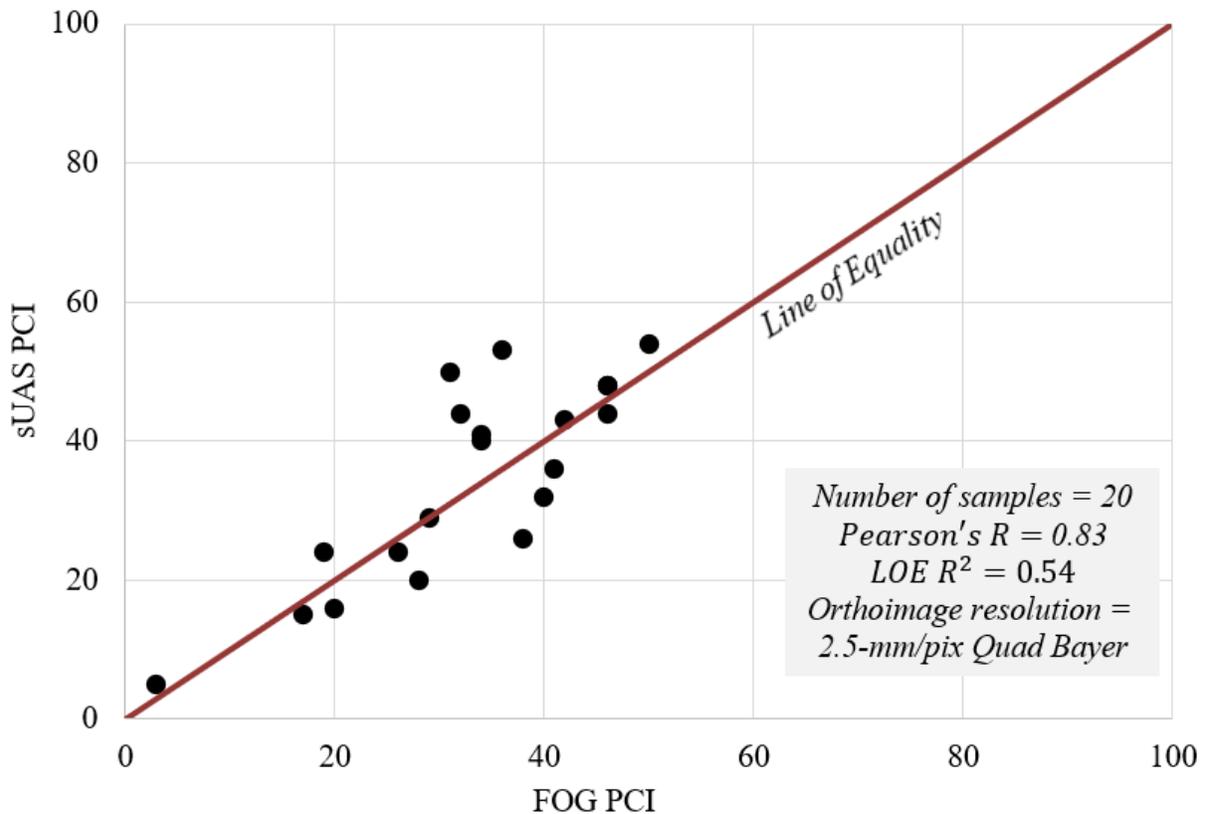


Figure 17. Foot-on-Ground PCI vs sUAS PCI Calculated Using 2.5-mm/pix Data from ONZ

## 2.4 CUSTER AIRPORT IN MARCH 2021

### 2.4.1 Objectives

The research team collected data from Custer Airport, Monroe, Michigan (TTF), at two different times. The first data collection was conducted in March 2021. It occurred on March 12 and March 22, 2021, because wind gusts above 40 kmph on the first day limited the research team's data collection efforts. The field demonstrations plan had the following objectives:

- Deploy and study the viability of the platforms and sensors that are available to the research team
- Evaluate the performance of available sUAS platforms and sensors for various distress visualizations
- Study the effect of different flight altitudes and data resolutions on distress identification
- Narrow the list of sensors and platforms recommended in task 2 based on the conclusions from field demonstrations at ONZ

### 2.4.2 Field Demonstration on March 12, 2021

The main data collection objective for TTF was to perform flights capturing all of Runway 3/21 and all of Taxiway A (Sections 10 and 30 together), with each of these areas having flights occurring at different heights to help evaluate how different flight altitudes (and resulting resolutions) may help identify particular distresses while still allowing for rapid data collection. These flights included RGB optical cameras and thermal cameras as the primary sensors. An experimental test of a multispectral camera available from MTRI (a Tetracam Micro-MCA6) was also completed to help evaluate its potential value for distress detection. The list of data collected at TTF in March 2021 are presented in Table 4. As the Table 4 shows, high-resolution sample unit data were collected from Runway 3/21 sample unit 53 (RW321 SU 53) and Taxiway A Section 10 sample unit 23 (TWA-10 SU 23) and 25 (TWA-10 SU 25). This high-resolution data collection aimed to narrow down the list of sensors for further deployment in future airports. The Taxiway A had an AC pavement system whereas Runway 3/21 had an Asphalt overlay over asphalt concrete (AAC) pavement system.

The research team traveled from MTRI, Ann Arbor, Michigan, to TTF on March 12, 2021, for sUAS data collection. One team member traveled from Ames, Iowa, to Ann Arbor, Michigan, joining the remaining team members. The research team acquired the necessary permission to fly sUAS at the airport by coordinating with the airport manager in the weeks leading up to the data collection, and the airport manager issued a Notice to Airmen (NOTAM) for the date of the sUAS data collection. A stand-up safety briefing was led by the remote pilot in command and attended by the collection team upon arriving at the airport (Figure 18). This standard briefing was conducted at the start of each data collection day at all airports visited in this research. The data collection team closely monitored the weather in the week leading up to the scheduled data collection, focusing on the temperature and wind gust speed, which varied from 9 °C to 12 °C and 16 kmph to 40.2 kmph, respectively.

Table 4. Summary of sUAS Data Collection at TTF in March 2021

Target Areas	sUAS Platforms	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
TWA-10 SU 23 and SU 25	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	18.3	1.5	6
		FLIR Vue Pro R	18.3	14.3	N/A
		Tetracam multispectral	18.3	10	N/A
RW321 SU 53	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	9.1	0.8	3
			18.3	1.5	6
		FLIR Vue Pro R	18.3	14.3	N/A
	Tetracam multispectral	18.3	10	N/A	
	Mavic 2 Enterprise	12-mp optical RGB + 120x160 thermal	15.3	4.9	19.6
	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	18.3	2.3	9.2
Taxiway A	Mavic 2 Pro	20-mp optical RGB	24.4	5.7	19.1
			30.5	7.2	29.1
Runway 3/21	Mavic 2 Pro	20-mp optical RGB	24.4	5.7	23
			30.5	7.2	19.1

Non-shaded data were collected on March 12, 2021; shaded data were collected on March 22, 2021.

RW321 = Runway 3/21

TWA-10 = Taxiway A Section 10

AGL = Above ground level

DEM = Digital elevation model



Figure 18. Safety Briefing at the TTF Airfield Before Beginning Fieldwork

After arriving at TTF, one part of the team (the pilot and drone safety observer) focused on sUAS data collection while the rest of the team placed GCPs and recorded location data from at the

locations shown in Figure 19. The standard safety measures were taken as outlined in the sUAS data collection safety plan (Appendices E and F). The data were collected during the pandemic, and the team maintained social distancing and followed federal, state, and local COVID-19 safety guidelines.

Three sets of sUAS flights equipped with different sensors were successfully deployed to collect data on March 12, 2021. These included (a) a Mavic 2 Pro with its integrated 20-mp optical RGB camera, (b) a Bergen Hexacopter with a Nikon D850 45.7-mp optical RGB camera with 50-mm prime lens mounted, and (c) a Mavic 2 Enterprise Dual with an integrated 12-mp optical RGB camera and FLIR 120x160 thermal sensor (DJI, 2020b). The Mavic 2 Enterprise Dual is an older model with lower resolutions than the new M2EA that became available later in this project.

The Bergen Hexacopter platform was used to carry the Nikon D850 optical RGB camera with a 50-mm prime lens to collect sUAS data of the sample units, shown in Figure 19, from 18.3-m altitude. The flights were conducted manually by an experienced sUAS pilot. The sample units were close to one another, and together they had all asphalt concrete (AC) pavement distresses recorded at TTF.

Upon collecting the data with the Bergen Hexacopter platform, sample unit data collection was attempted with both pre-planned and manual flights using the mdMapper1000+ with 42.4-mp optical RGB Sony RX1R-II (Microdrones, 2021). The flights were aborted because of high wind speeds, unsuitable for a stable flight of the mdMapper1000+ drone, which appeared to be more impacted by wind gusts than the older Bergen Hexacopter unit (wind gusts up to 40.2 kmph).

The Mavic 2 Pro, with its 20-mp optical RGB camera, was used to collect RGB photos of Runway 3/21 and Taxiway A from 24.4 m above ground level (AGL). The research team created a pre-planned data-collection project file on freely available drone flight assistant software, Pix4D Capture, to estimate survey time and allow automatic operation of the drone (PIX4D, 2021). Several projects were created on Pix4D Capture software prior to the survey date to estimate flight times required for the survey of each discrete area. An Android tablet computer with the Pix4D Capture software installed and operating was connected to the Mavic 2 Pro drone controller at the data-collection site. The software created a flight plan that enabled the drone to fly automatically, with the pilot ready to take control if needed. The Mavic 2 Pro flew over Runway 3/21 and Taxiway A, capturing images that were saved into the drone's onboard memory card, usually 128 GB in size. A total of 7 flights, ranging from 5 minutes to 14 minutes, were made to collect Runway 3/21 sUAS data, while 2 flights of 15 minutes and 19 minutes were required to collect sUAS data for Taxiway A. Mavic 2 Pro batteries were swapped between the two flights and recharged with a generator as needed.

Similar to the Mavic 2 Pro flight plan, another flight plan was created using Pix4D Capture to collect sample unit optical RGB and thermal imagery using the Mavic 2 Enterprise at 15.2-m altitude over the RW321 SU 53. The Mavic 2 Enterprise completed the automated mission over RW321 SU 53 in 9 minutes. Most of the data had 80% forward overlap and a 70% side overlap for better reconstruction and orthophoto creation. This was recommended for all other airports.

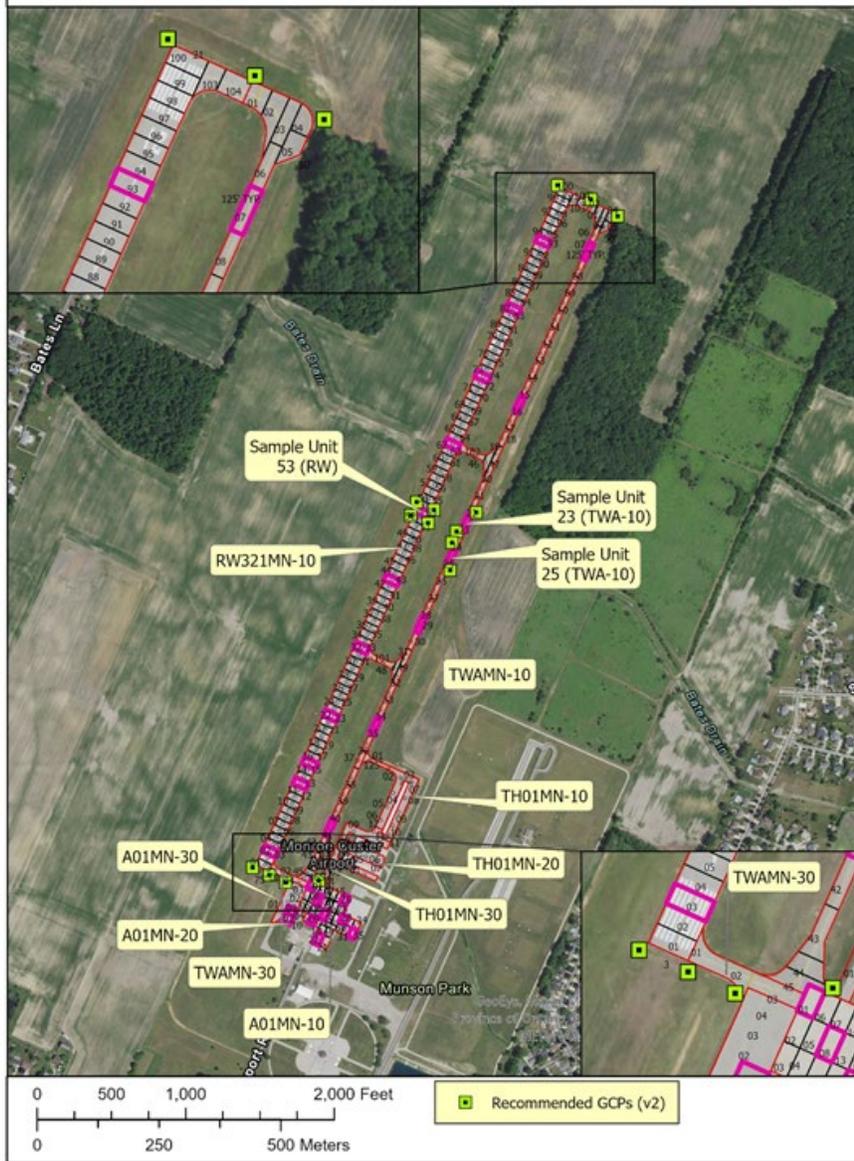


Figure 19. Sample Unit Focus Area and Recommended GCP Locations at TTF in March 2021

#### 2.4.3 Field Demonstration on March 22, 2021

The MTRI research team traveled to TTF on March 22, 2021 for a second sUAS data collection effort. The research team acquired the necessary permission from the airport manager to fly sUASs over the airport, and the airport manager issued a NOTAM for the date of the survey. The temperature and wind speed on the survey date were favorable for deploying large sUASs, which are susceptible to wind speed and wind gust. The recorded temperature varied between 13 °C and 20 °C, whereas the recorded wind speed was from 4.8 kmph to 17.6 kmph, with gusts up to 31.1 kmph in the afternoon.

Five sUAS systems were successfully deployed to collect data on March 22, 2021: (a) a Mavic 2 Pro with its integrated 20-mp optical sensors, (b) a Bergen Hexacopter with a Nikon D850 45.7-mp optical RGB Camera with 50-mm prime lens mounted, (c) a Bergen Hexacopter with a FLIR VUE Pro R, (d) a Bergen Hexacopter with a Tetracam multispectral camera, and (e) an mdMapper1000+ with a 42.4-mp optical RGB Sony RX1R-II. Details of the focus areas, collected data type, sUAS platform, and sensors are already provided in Table 4.

As shown in Figure 20, the Bergen Hexacopter platform was used to carry a Nikon D850 optical RGB camera with a 50-mm prime lens to collect sUAS data on RW321 SU 53 from 9.1 m AGL. A FLIR Vue Pro R thermal sensor was mounted on the Bergen Hexacopter to collect thermal data from 18.3 m AGL on three sample units: TWA-10 SU 23, TWA-10 SU 25, and RW321 SU 53. Additionally, the Tetracam 6-band multispectral sensor was mounted on the Bergen Hexacopter to collect multispectral data from 18.3 m AGL on TWA-10 SU 23, TWA-10 SU 25, and RW321 SU 53. The Bergen Hexacopter sUAS platform does not support software-controlled automatic flight; therefore, an experienced and FAA-licensed unmanned pilot manually operated the sUAS during the flight. The flight times for the thermal data collection of the RW321 SU 53 and TWA-10 SUs 23 and 25 were 4 minutes and 7 minutes, respectively. The mdMapper1000+ with 42.4-mp optical RGB Sony RX1R-II was flown at 18.3 m AGL to collect optical RGB images of the same sample. Because of high wind gusts and turbulence on the airfield, the research team suspended mdMapper1000+ data collection after collecting RW321 SU 53 optical RGB data.



Figure 20. High-resolution sUAS Data Collection with mdMapper1000+ and Bergen Hexacopter sUAS Platform

Similar to previous data collection efforts, multiple automatic data collection missions were created for Mavic 2 Pro on Pix4D Capture and used to collect optical RGB photos of Runway 3/21 and Taxiway A from 30.5 m AGL. A total of four flights, ranging from 10 minutes to 16 minutes, were required for the Mavic 2 Pro to collect the Runway 3/21 sUAS data. The Mavic 2 Pro Taxiway A data were captured with a single 17-minute flight.

APTech's PCI survey team traveled to TTF and conducted an airfield pavement distress FOG survey using ASTM D5340-20 standard on January 18 and 19, 2021. The team located, identified, and recorded pavement distresses onto their handheld GPS-enabled field data collection tablet. The data were processed, and the PCI values for all sample units and branches of the airfield pavement were calculated based on the ASTM D5340-20 standard. Eleven sample units from Runway 3/21 and seven from Taxiway A were surveyed. Both the airfield pavement sections had an AC surface, and the PCI values varied from 66 to 90 for Runway 3/21 and from 56 to 63 for Taxiway A. The predominant distresses were longitudinal and transverse (L&T) cracks, swelling, weathering, raveling, and depressions. Eight apron sample units were also surveyed, but sUAS data collection was not focused on this area.

## 2.5 CUSTER AIRPORT IN MAY 2021

### 2.5.1 Objectives

The research team collected full high-resolution data in May 2021 at TTF to enable use of a new sUAS and to test simultaneous flights. A particular set of sUASs and their flight altitude were selected for this field demonstration based on the conclusions from earlier field demonstrations executed at ONZ and TTF. The objectives of this field demonstration are listed below:

- Full data collection using M2EA
- Evaluate the performance of the thermal data collected using M2EA
- Evaluate the applicability of simultaneous data collection using more than one sUAS system

### 2.5.2 Field Demonstration in May 2021

The research team traveled to TTF to collect complete field data on May 21, 2021. The main focus of this data collection was to collect the complete data of Runway 3/21 and Taxiway A with a single sUAS. The research team contacted the airport authority in advance and was welcomed to collect data again. TTF is a civil aviation airport and sees only a few airplane operations daily, enabling the team to plan and complete data collection in 1 day. The wind speeds in the morning were relatively low, fluctuating from 8 kmph to 16 kmph, and facilitated the flight of mdMapper1000+, which is susceptible to high wind speed. The highest recorded wind speed was 18 kmph.

The mdMapper1000+ with 42.4-mp optical RGB Sony RX1R-II camera was flown over RW 3/21 SU 53, TWA SU 23, and TWA SU 25 at 22 m and 30.5 m to collect 3 mm/pix and 5 mm/pix as requested by FAA Technical Points of Contact (TPOCs). Three different flights were conducted and took 15 minutes total. An 80% forward overlap and 70% side overlap were used. Afterward, two M2EAs were used for complete RGB optical data collection from Runway 3/21 and Taxiway A at 15.2 m. The same systems were used to collect sample unit thermal data from 24.4 m with the 640x512-pixel stereo thermal sensor. The data were simultaneously collected with two pilots in command, each with a dedicated visual observer. A total of 10 AeroPoints were used, as shown in Figure 21, which also shows the sample units. The AeroPoint locations were also used to adjust

the location information of the images recorded with the sUAS' onboard GPS and to generate orthophotos. The flight details and data collection focus areas are provided in Table 5.

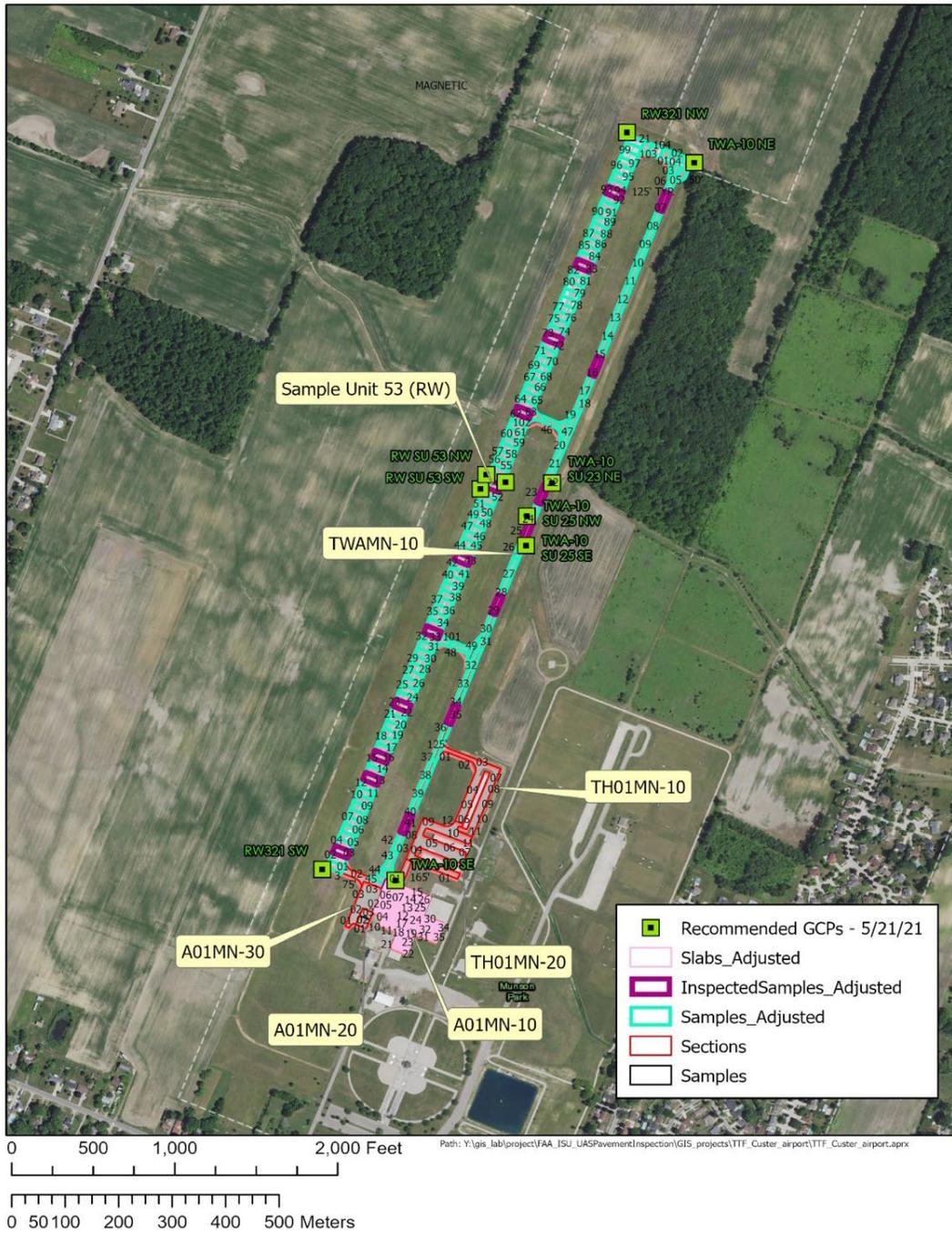


Figure 21. Sample Unit Focus Area and Recommended GCP Locations at TTF in May 2021

Table 5. Summary of sUAS Data Collection at TTF in May 2021

Target Areas	sUAS Platform	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
TWA-10 SU 23 and SU 25, and RW321 SU 53	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	30.5	5.0	15
	M2EA	640x512 thermal	24.4	31.5	N/A
TWA-10 SU 23 and SU 25	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	22	3.0	10
Taxiway A	M2EA	48-mp optical RGB Quad Bayer	15.2	*2.5	10
RW321	M2EA	48-mp optical RGB Quad Bayer	15.2	*2.5	10

TWA-10 = Taxiway A Section 10

RW321 = Runway 3/21

SU = Sample unit

AGL = Above ground level

DEM = Digital elevation model

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

## 2.6 RESULTS AND DISCUSSIONS OF CUSTER AIRPORT DATA ANALYSIS

### 2.6.1 March 2021 Data Analysis

All data collected from TTF were imported into Agisoft Metashape separately, and image locations were updated using the GCPs. The GCP data were collected with a combination of the Trimble GeoExplorer 6000 and AeroPoints. The data were processed to export optical RGB orthophoto and DEM. The DEM images were further processed in ArcGIS Pro to create hillshades for better visualization of elevation changes. Different sets of RGB optical data were compared in ArcGIS Pro to check their capabilities for airfield pavement distress detection and severity rating. The results of the analysis of these data are discussed in Section 2.6.2, along with results of later data analysis.

- Collecting 0.8-mm/pix data with the Nikon D850 mounted on the Bergen Hexacopter flying at 9.1 m AGL was very slow, requiring many closely spaced images to create the needed image overlap for orthophoto construction, and a complete orthophoto of the RW321 SU 53 was not constructed properly due to difficulties in achieving a consistent overlap when manually flying this older sUAS system. The RGB orthophoto of this resolution was found to be useful for clearly viewing both sealed and unsealed L&T cracks and measuring their width for crack severity determination (Figures 22 through 24).
- The Bergen Hexacopter carrying the Nikon D850 and providing 1.5-mm/pix data performed slightly better than the 2.3 mm/pix of the mdMapper1000+ data collected at 18.3 m determination (Figure 22. to Figure 24). However, the difference in the performance of their associated DEM (6 mm/pix for Nikon D850 and 9.2 mm/pix for the mdMapper’s Sony camera) were much more noticeable, especially for delineation of the width of sealed

and unsealed L&T cracks (Figures 22 and 23). Both the resolutions are recommended for future airport pavement data collection.

- Both optical RGB orthophotos created using data collected by the Mavic 2 Pro and Mavic 2 Enterprise could be used to identify sealed and unsealed L&T cracks. However, the width of narrow sealed cracks could not be measured because of comparatively lower orthophoto resolution (4.9 mm/pix – 7.2 mm/pix) (Figures 22 and 23).
- Mavic 2 Pro’s 5.7 mm/pix and 7.2 mm/pix, and Mavic 2 Enterprise’s 4.9-mm/pix RGB orthophoto can be used only to detect both sealed and unsealed L&T Cracks, but not to detect associated severities (Figures 22 through 24).
- 29-mm/pix and 23-mm/pix DEMs generated using Mavic 2 Pro data collected at 24.4-m and 30.5-m heights, respectively, offered almost no value for any distress detection. In addition, DEM data of 19 mm/pix collected with the Mavic 2 Enterprise Dual provided minimum visual information. Nikon D850 data captured at 9.1 m and 18.3 m with resolutions of 3 mm/pix and 6 mm/pix, respectively, were useful to detect delaminated areas and L&T cracks on the sample units. In addition, mdMapper1000+’s 9.2-mm/pix data also were very useful for L&T cracks detection (Figure 25). Thus, any DEM with a resolution finer than 20 mm/pix was recommended for future data collection.
- Regardless of the data format, swell, raveling, and weathering distresses were found to be difficult to identify using the collected data (Figure 26).
- The FLIR Vue Pro R thermal camera was mounted on the Bergen Hexacopter and flown at 18.3 m AGL over all three sample units. The resulting images had a resolution of 14.3 mm/pix, which proved to be sufficient for the identification of both sealed and unsealed L&T cracks (Figure 27). In addition, a sealed (and white-painted) L&T crack that ran through white-painted pavement markings was visible only in the thermal imagery (and not optical imagery) because it records temperature differences between cracks and their neighboring areas in both painted and unpainted areas.

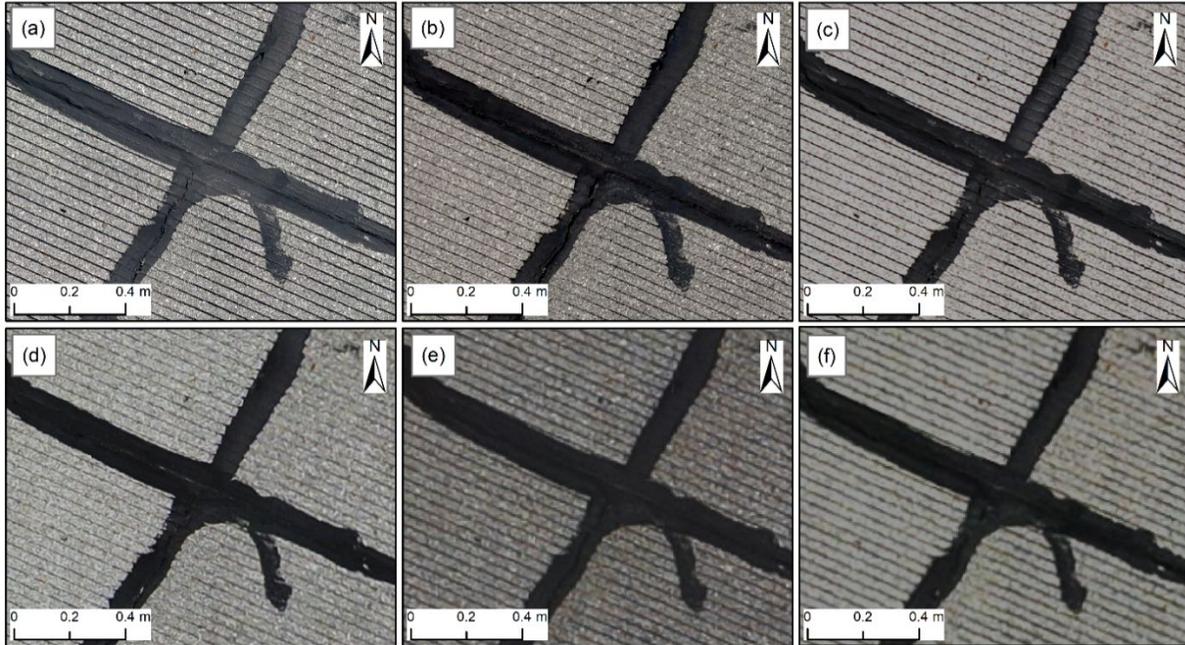


Figure 22. Sealed L&T Cracks (Medium-severity on Top Left Side, Low-severity on Top Side) and Low-severity Weathering on AAC Pavement at TTF: (a) 0.8-mm/pix Orthophoto, (b) 1.5-mm/pix Orthophoto, (c) 2.3-mm/pix Orthophoto, (d) 2.5-mm/pix Orthophoto, (e) 4.9-mm/pix Orthophoto, and (f) 5.7-mm/pix Orthophoto

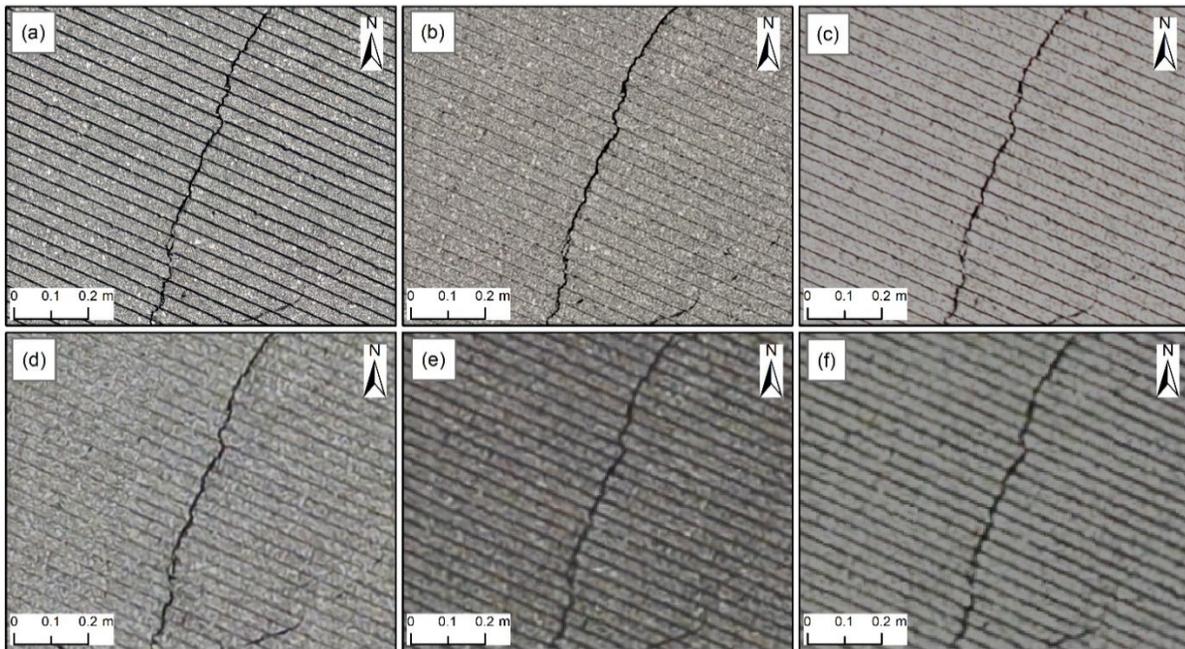


Figure 23. Low-severity Unsealed L&T Cracks and Low-severity Weathering on AAC Pavement at TTF: (a) 0.8-mm/pix Orthophoto, (b) 1.5-mm/pix Orthophoto, (c) 2.3-mm/pix Orthophoto, (d) 2.5-mm/pix Orthophoto, (e) 4.9-mm/pix Orthophoto, and (f) 5.7-mm/pix Orthophoto

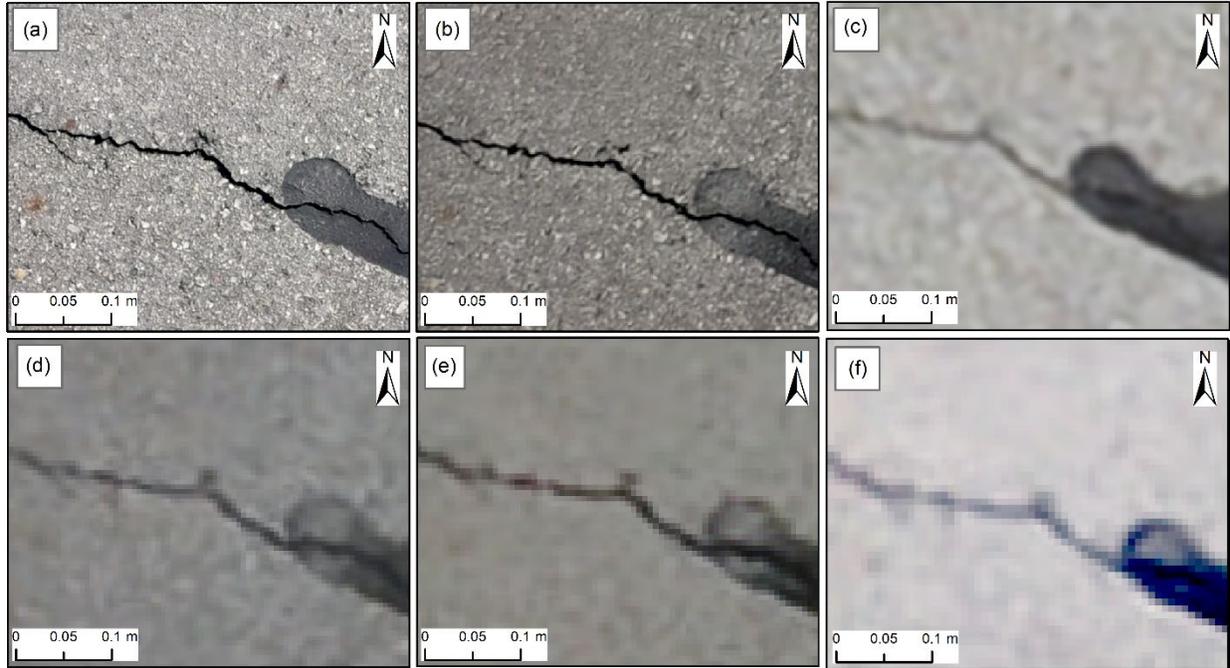


Figure 24. Medium-severity Unsealed L&T cracks and Low-severity Weathering on AAC Pavement at TTF: (a) 0.8-mm/pix Orthophoto, (b) 1.5-mm/pix Orthophoto, (c) 2.5-mm/pix Orthophoto, (d) 4.9-mm/pix Orthophoto, (e) 5.7-mm/pix Orthophoto, and (f) 7.2-mm/pix Orthophoto

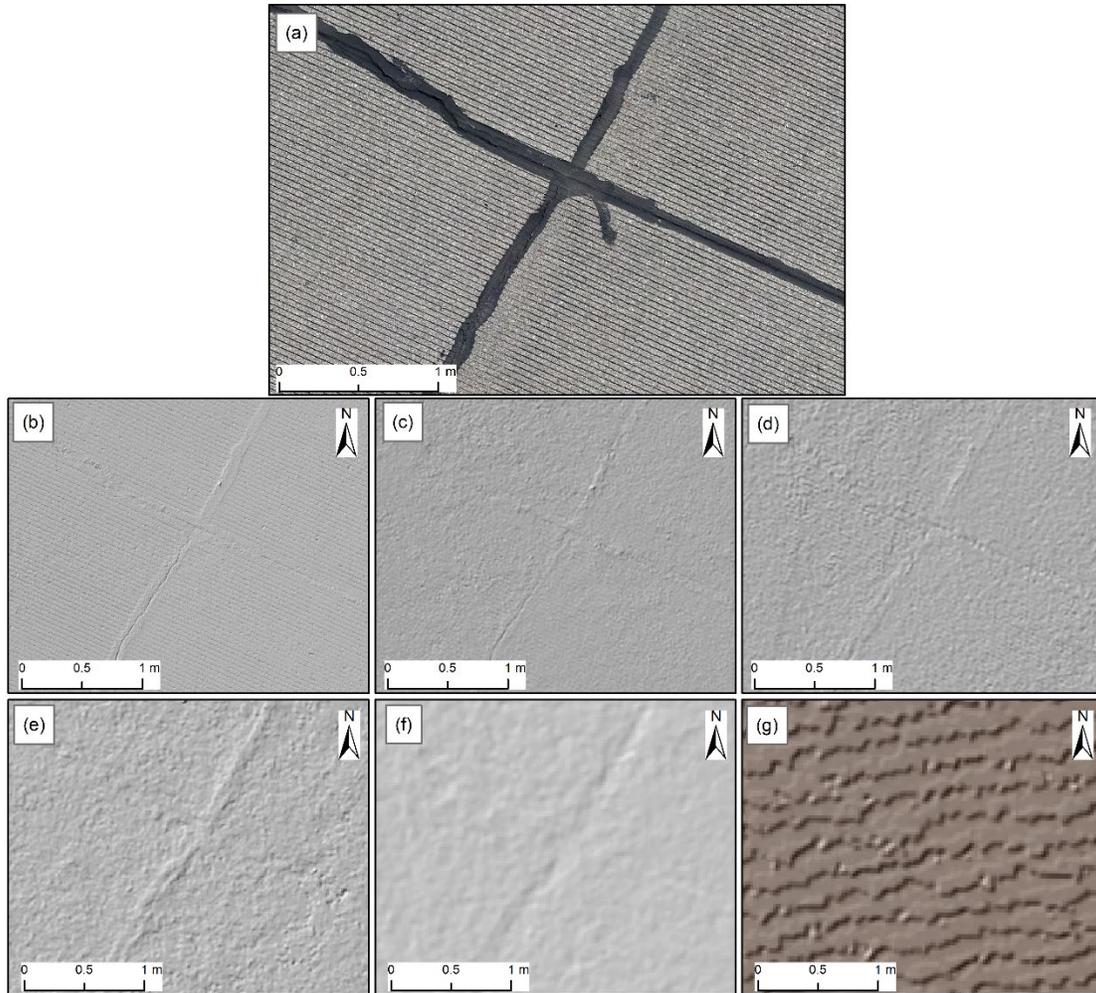


Figure 25. Low-severity Sealed L&T Cracks and Weathering on AAC Pavement at TTF: (a) 0.8-mm/pix Orthophoto, (b) 3-mm/pix DEM, (c) 6-mm/pix DEM, (d) 9.2-mm/pix DEM, (e) 10-mm/pix DEM, (f) 19.6-mm/pix DEM, and (g) 19.1-mm/pix DEM

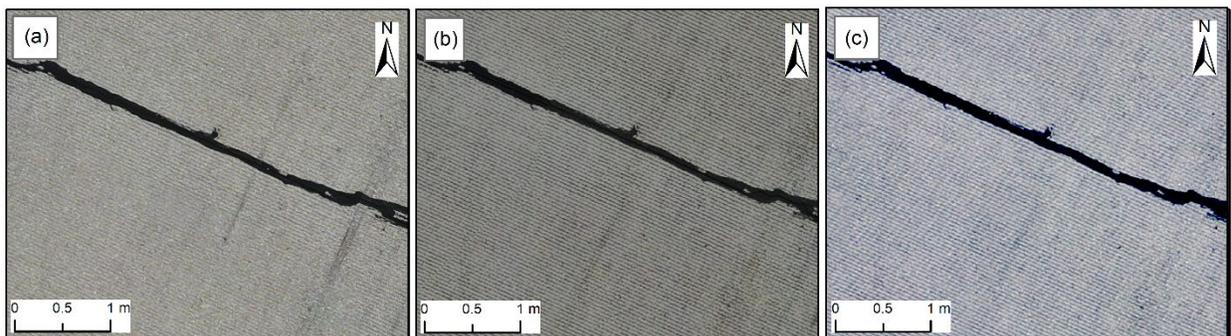


Figure 26. Low-severity Swell and Low-severity Weathering on AAC Pavement at TTF: (a) 2.5-mm/pix Orthophoto, (b) 5.7-mm/pix Orthophoto, and (c) 7.2-mm/pix Orthophoto

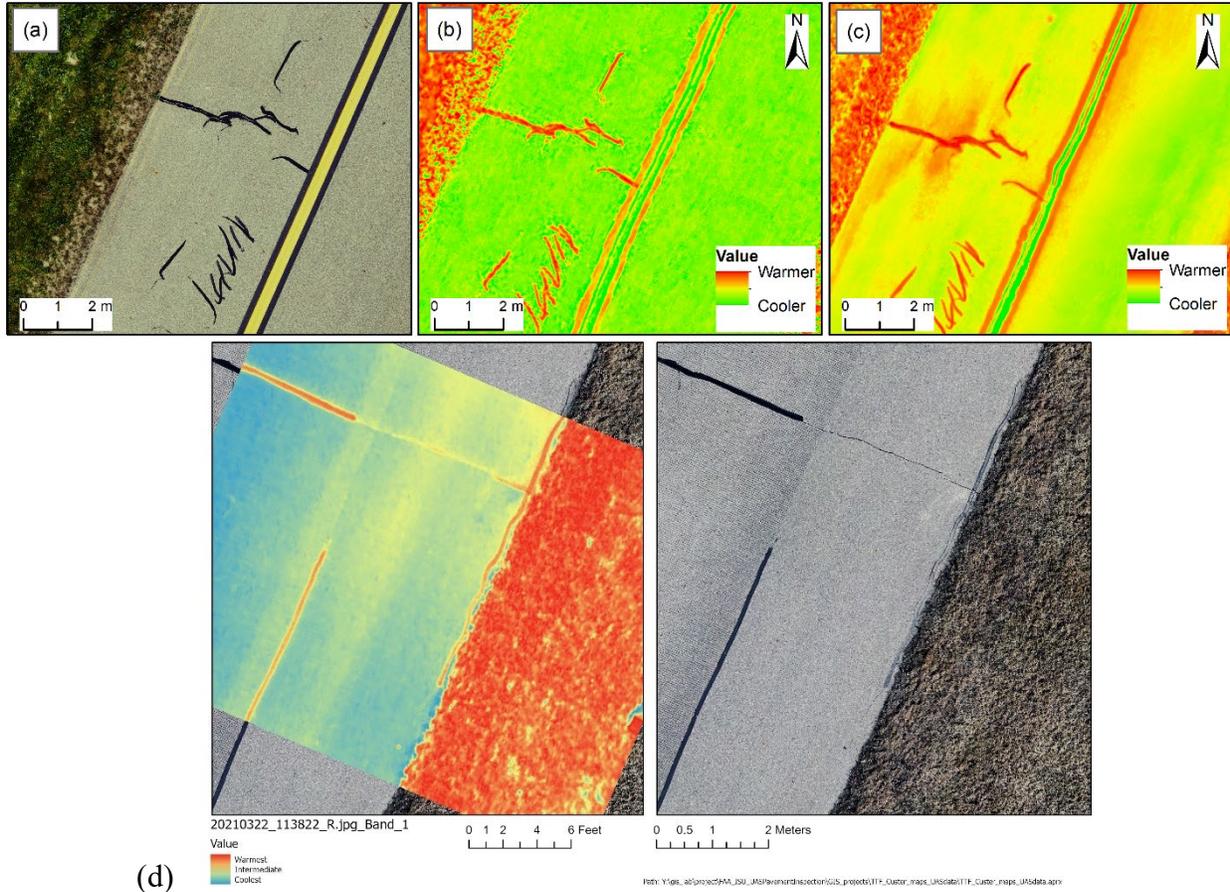


Figure 27. Sealed L&T Cracks on AC Pavement in Taxiway A Sample Unit 23 at TTF: (a) 1.5-mm/pix Orthophoto, (b) 31-mm/pix Stereo Thermal, (c) 14-mm/pix Stereo Thermal, and (d) Alternate View of Cracks in the 14-mm/pix Stereo Thermal Results Compared to an Orthophoto of the Same Area

The TTF data collection helped the research team to recommend the following platform, sensor, and altitudes for the full data collection:

- Bergen Hexacopter with Nikon D850 45.7 mp flown at 18.3 m AGL, or a system with equivalent optical RGB resolution capability
- Bergen Hexacopter with FLIR Vue Pro R 640x512 flown at 18.3 m AGL, or a system with equivalent thermal resolution capability
- M2EA with a 48 mp effective camera and 640x512 thermal system, flown at 15.2 m AGL, may be ideal for deployment; this could potentially replace the need for the older, larger, and slower Bergen systems that exclusively require manual flight
- DJI Mavic 2 Pro with 20 mp or DJI Mavic 2 Enterprise with 12-mp camera flown at 15.2 m AGL; however, these are likely to be redundant if the M2EA dual imaging system meets expectations

- mdMapper1000+ with Sony 42.4-mp Sony RX1R-II at 30.5 m AGL. This system has a longer duration (up to 30 minutes) flight time, is larger, and is a faster platform that may replace the need for the Bergen system. However, it needs wind conditions consistently below 24 kmph, limiting its deployment practicality. Similar systems, such as the Tarot X6, were becoming available for the project, and the research team expected that to replace the need for the mdMapper1000+ system

The effect of using these platforms on recommended resolutions for the rest of the data collection efforts can be summarized as:

- Any system and elevation that produces RGB orthophoto outputs with smaller (better) than 5-mm/pix resolution or better providing the best results for distress detection and rating
- Any system and elevation that produces DEM outputs with smaller (better) than 20-mm/pix resolution
- Any system and elevation that produces thermal merged imagery outputs with smaller (better) than 20-mm/pix resolution

Fixed-wing systems could potentially meet the abovementioned recommendations if they can be safely operated in an airport environment. The survey team found that the rapid landing capabilities of multi-rotor systems are helpful for operating at airports. Some newer fixed-wing systems start as vertical take-off and landing aircraft and then transition into the fixed-wing flight, and these could potentially provide the rapid response to changing air traffic and weather conditions that are sometimes needed when collecting sUAS data at operating airports.

### 2.6.2 May 2021 Data Analysis

The data collected from TTF in May 2021 were separately imported into Agisoft Metashape and processed to create RGB optical orthophotos and DEMs. These data were compared with the sUAS data collected in March 2021. The comparisons are shown in Figures 22 through 25 above. The following lessons were learned from the comparisons:

- The 2.5-mm/pix data collected using the M2EA provided less visual information than similar resolution data collected using mdMapper1000+ with a 42.4-mp optical RGB Sony RX1R-II camera. The M2EA's 48-mp sensor is a Quad Bayer sensor and has an actual resolution of 12 mp. Therefore, the Mavic 2 Pro with a 20-mp integrated RGB optical camera at 15.2 m was recommended for future data collection.
- The FLIR Vue Pro R and thermal sensor of the M2EA have identical resolution: 640x512. The FLIR Vue Pro R had to be mounted on the Bergen Hexacopter because of the combined weight of the sensor and its dedicated battery. This sUAS was manually operated over sample units with the older flight controller. In addition, the FLIR Vue Pro R does not collect and embed GPS information in its thermal images, making them challenging to process into a merged, georeferenced output geospatial layer. Conversely, the stereo thermal camera data of M2EA can be collected using mission-planning software, and all captured images have embedded GPS data, making it easier to process into a merged,

georeferenced output layer. In addition, the 31.5-mm/pix stereo thermal data of the M2EA provides useful visual information regarding the location of the L&T cracks on the AC surface and the cracks under the pavement marking (Figure 27). Considering all these factors, the M2EA was recommended for stereo thermal data.

Based on the data collected at TTF on March 2021 and May 2021, the airfield pavement distresses shown in Table 6 were found to be detectable.

Table 6. Summary of the Findings of TTF

ASTM D5340 Distress	Severity	Resolution Tested (mm/pix)		Distress Detected in Maximum Resolution (mm/pix)		Remarks
		Orthophoto	DEM	Orthophoto	DEM	
L&T cracking (48)	L	0.8, 1.5, 2.3, *2.5, 4.9, 5.7, 7.2	3, 6, 9.2, 10, 19.6, 23, 29.1	7.2	9.2	Figure 22 to Figure 25
	M				19.6	
Raveling (52)	L	0.8, 1.5, 2.3, *2.5, 4.9, 5.7, 7.2	3, 6, 9.2, 10, 19.6, 23, 29.1	ND	ND	
	M				*2.5, 5.7, 7.2	10, 23, 29.1
Swell (56)	L	*2.5, 5.7, 7.2	10, 23, 29.1	ND	ND	Figure 26
Weathering (57)	L	0.8, 1.5, 2.3, *2.5, 4.9, 5.7, 7.2	3, 6, 9.2, 10, 19.6, 23, 29.1	ND	ND	Figure 22 to Figure 26
	M				*2.5, 5.7, 7.2	

AGL = Above ground level

DEM = Digital elevation model

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

There were 18 priority sample units selected for high-resolution sensing on Runway 3/21 and Taxiway A, where FOG PCI data were also collected. The 2.5-mm/pix RGB optical data collected with the M2EA was visually observed in ArcGIS Pro. Each airfield pavement distress on the sample units was quantified, and associated severity levels were detected. The recorded data were used to estimate the PCI value by following the guidelines outlined in ASTM D5340-20. All sample units except for one had sUAS data observed PCI values higher than the FOG data PCI, as shown in Figure 28. The main contributors to the higher PCI values were missing weathering, swell, and raveling that could not be detected from the sUAS data with 2.5-mm/pix resolution.

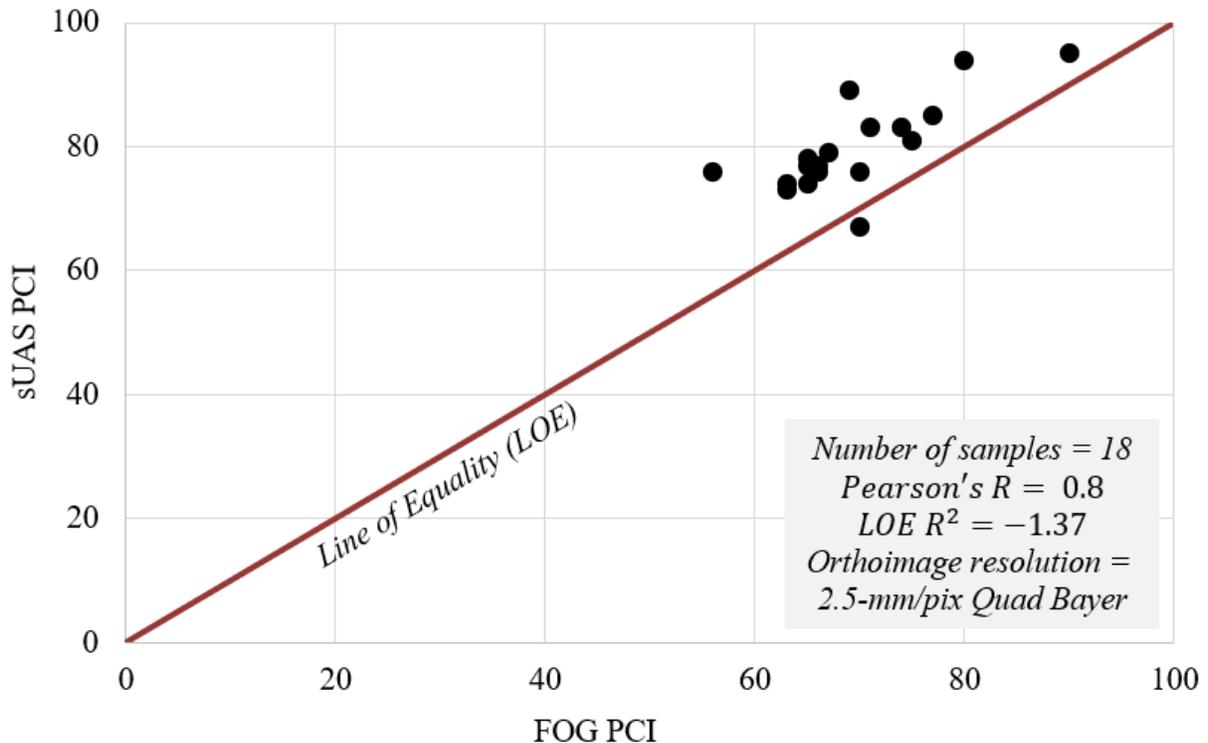


Figure 28. Foot-on-Ground PCI vs sUAS PCI Calculated Using 2.5-mm/pix Data from TTF

### 3. FIELD DEMONSTRATION IN ILLINOIS

#### 3.1 COLES COUNTY MEMORIAL AIRPORT IN JUNE 2021

##### 3.1.1 Objectives

The research team collected sUAS data from Coles County Memorial Airport, Mattoon, Illinois (MTO), on June 16 and 17, 2021. MTO is the largest of the airports the research team surveyed. Based on the lessons learned from ONZ and TTF, the following objectives were identified for this data collection:

- Collect sUAS data of the complete airfield pavements with a single sUAS system
- Evaluate the performance of the Mavic 2 Pro for complete optical data collection
- Evaluate the feasibility of data collection with three sUAS systems simultaneously
- Evaluate the performance of available sUAS platforms and sensors for various types of distress visualization

##### 3.1.2 Field Demonstration in June 2021

Airfield pavement data were collected from MTO using multiple sUAS systems on June 16 and 17, 2021. The airport manager was contacted, and a NOTAM was issued for this data

collection. MTO had specific safety guidelines and protocols every crew member on airport property must follow. All members of the data collection team completed the safety training conducted by the airport manager on June 16, 2021, before entering the airfield. Standard sUAS and airport safety plans were also followed (Appendices I and J). Because of the size and frequency of air traffic at the MTO, the data collection focused on Runway 6/24, Taxiway D, and Apron Section 3, along with high-resolution priority sample units, mainly on taxiways. The data were also collected over a two-day period: Runway 6/24, Taxiway D, and Apron Section 3 data on the first day and high-resolution sample unit data collection on the second day. The original data collection plan included high-resolution sample unit data collection over Runway 6/24 Section 4, sample units 01, 02, and 03. However, the pavement areas were recently reconstructed, and the research team collected Taxiway D Section 5, sample units 01 and 02 instead. A Mavic 2 Pro with 20-mp integrated optical RGB sensor was chosen as the main sUAS system for full data collection from the Runway 6/24 and Taxiway D. RGB optical and thermal data were collected using M2EA from Apron Section 3 at 15.2 m and 24.4 m, respectively, to further evaluate this system. The high-resolution priority sample unit data were also collected using the same system from the same altitude, as shown in Table 7. A Nikon D850 45.7-mp camera mounted on the Bergen Hexacopter was flown at 18.3 m to collect optical RGB data with 1.5-mm/pix resolution. In addition, mdMapper1000+ with Sony RX1R-II 42.4-mp optical RGB camera was also flown at 30.5 m for 5-mm/pix data collection. The details of the sUAS platforms, sensors, and flight altitudes used in the data collection are shown in Table 7.

Table 7. Summary of sUAS Data Collection at MTO

Target Areas	sUAS Platforms	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
TWD3MTO-01 SU 01 and 02, TWD4MTO SU 01, RW6MTO-04 SU 01, 02, and 03	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	18.3	1.5	6
	M2EA	48-mp optical RGB	15.2	*2.5	4.9
	M2EA	512x640 thermal	24.4	31	N/A
	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	30.5	5	15
Runway 6/24	Mavic 2 Pro	20-mp optical RGB	15.2	3.6	14.3
Taxiway D	Mavic 2 Pro	20-mp optical RGB	15.2	3.6	14.3
Apron section 3	Mavic 2 Pro	20-mp optical RGB	15.2	3.6	14.3

RW6MTO-04 = Runway 6/24

TWD3MTO = Taxiway D3

TWD4MTO = Taxiway D4

SU = Sample unit

AGL = Above ground level

DEM = Digital elevation model

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

The collected photogrammetric stereo overlapping image datasets of the complete Runway 6/24 and complete Taxiway D dataset collected with Mavic 2 Pro and Apron Section 3, and high-resolution dataset collected with M2EA were imported separately into Agisoft Metashape for

processing. The locations of the sUAS images were corrected using the location information of 10 AeroPoints (with built-in GPS) and 16 cloth GCPs placed at different sections of the airfield and location measured with Trimble GPS unit (Figure 29). The images were parallelly processed on multiple high-end desktop workstations to create optical RGB orthophotos and DEMs.

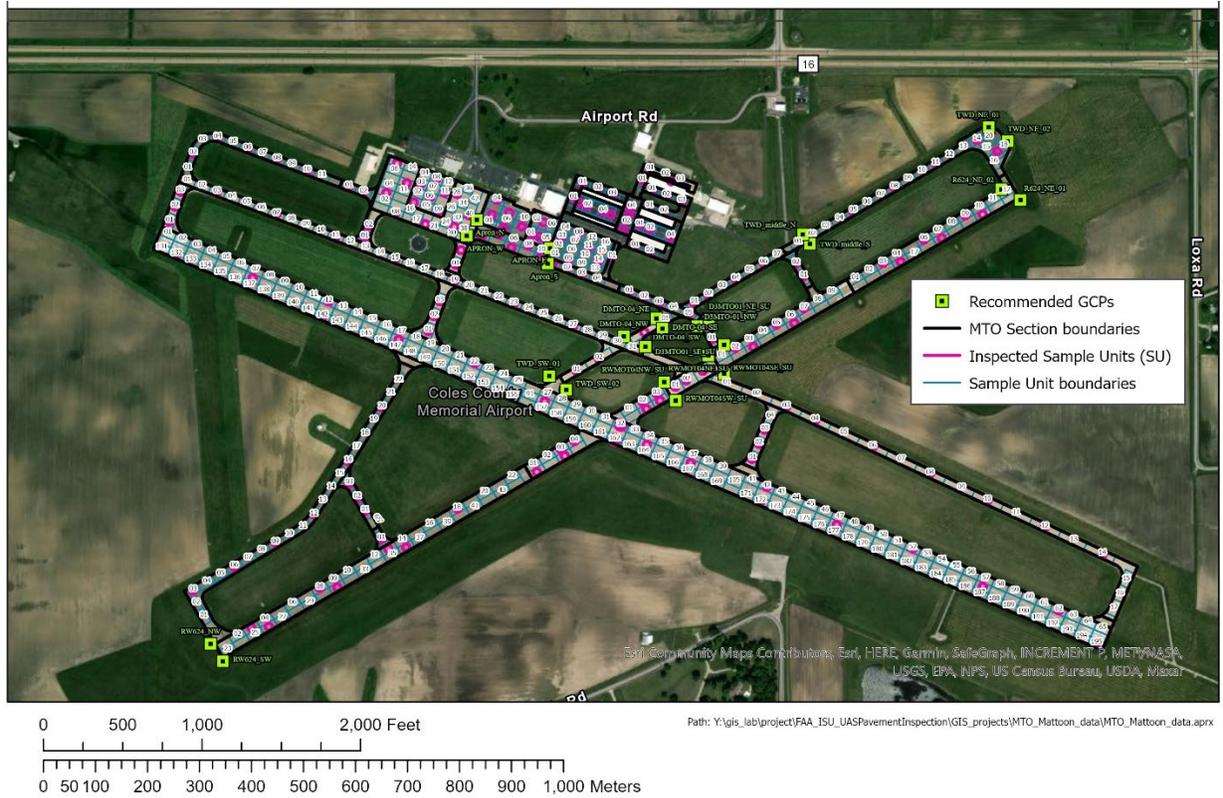


Figure 29. Recommended Locations for GCPs at MTO

APTech conducted an airfield pavement distress FOG survey at MTO. A two-person ground crew traveled from Urbana, Illinois, to MTO on July 5 and 6, 2021, and recorded the airfield distresses onto a handheld GPS-enabled tablet. The data were processed, and the PCI values for all sample units and branches of the airfield pavement were calculated based on the ASTM D5340-20 standard. The PCI values for the different sections of AC pavement ranged from 16 to 91, and the PCC pavement PCIs ranged from 40 to 84. A survey report was generated, including the types of distresses present on the sample unit and its estimated PCI value.

### 3.1.3 Results and Discussions

The PCI FOG data were collected from 28 sample units. The PCI FOG team collected the PCC pavement distress data of the Apron, but no sUAS data were collected there. The PCI FOG and sUAS data had 15 common sample units, and from them, 10 sample units were selected for further analysis. The new recorded distresses at MTO, which were not recorded at ONZ and TTF, were depression, shoving, shrinkage cracking, and joint spalling. The orthophoto, DEM, and hillshade DEM of the 10 sample units' images were imported to ArcGIS Pro. Each pavement distress was quantified, and its severity was determined using the data collected with Mavic 2 Pro over the

Runway and Taxiway and with M2EA over the Apron at 15.2 m altitude. The AC pavement system of the MTO was in poor condition, and extensive block cracking was reported. The FOG PCI team recorded L&T cracks in place of the block cracking to facilitate performance comparison of different sensors. In sUAS-based PCI calculation, the sample units were noted to have block cracking with associated severity. The distresses that were correctly detected and rated on the sUAS-based data are provided in Table 8.

Table 8. Summary of the Findings of MTO

ASTM D5340 Distress	Severity	Resolution Tested (mm/pix)		Distress Detected in Highest Resolution (mm/pix)		Remarks
		Orthophoto	DEM	Orthophoto	DEM	
Alligator cracking (41)	L	*2.5, 3.6	4.9, **14.3	3.6	ND	
Block cracking (42) and L&T cracking (48)	L	*2.5, 3.6	4.9, **14.3	3.6	ND	Figure 30 and Figure 31
	M	*2.5, 3.6	4.9, **14.3	3.6	ND	
	H	*2.5, 3.6	4.9, **14.3	3.6	4.9	
Raveling (52)	M	*2.5, 3.6	4.9, **14.3	ND	ND	
Weathering (57)	M	*2.5, 3.6	4.9, **14.3	ND	ND	
LTD cracks (63)	L	*2.5, 3.6	4.9, **14.3	3.6	ND	Figure 32
	M	*2.5, 3.6	4.9, **14.3	3.6	4.9	
Joint seal damage (65)	L	*2.5, 3.6	4.9, **14.3	ND	ND	
Shattered slab (72)	M	*2.5, 3.6	4.9, **14.3	3.6	4.9	Figure 33
Shrinkage crack (73)	N/A	*2.5, 3.6	4.9, **14.3	3.6	ND	Figure 33
Joint spalling (74)	L		4.9, **14.3	3.6	ND	Figure 34
	M	*2.5, 3.6	4.9, **14.3	3.6	ND	
Corner spalling (75)	L	*2.5, 3.6	4.9, **14.3	3.6	ND	

DEM = Digital elevation model

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

\*\*14.3-mm/pix DEM contained some reconstruction issues.

Based on the above-mentioned analysis, the following lessons were learned:

- L&T and block cracking of all severity levels were detected and rated in both 2.5-mm/pix and 3.6-mm/pix data as shown in Figures 30 and 31.
- Shoving was detected in 4.9-mm/pix hillshade DEM data generated using an optical orthophoto of 2.5-mm/pix data collected with M2EA.
- LTD cracks, shattered slabs, shrinkage cracking, and joint spalling were identifiable in both 2.5- and 3.6-mm/pix data (Figures 32 through 34). However, there is a possibility of missing shrinkage cracks in a similar resolution dataset (Figure 33).

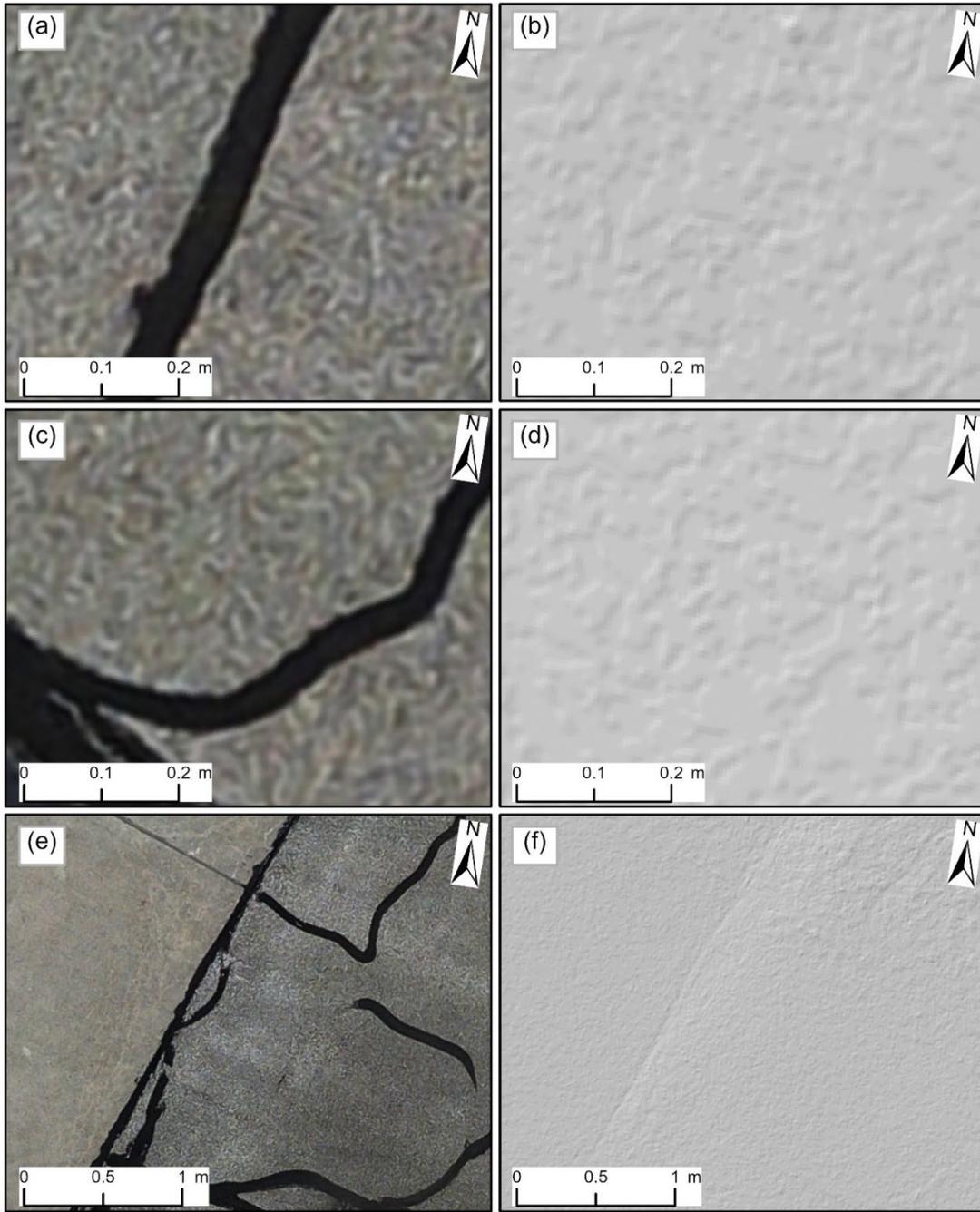


Figure 30. Low-severity L&T Cracks in (a) 2.5-mm/pix Orthophoto and (b) 4.9-mm/pix DEM; Medium-severity L&T Cracks in (c) 2.5-mm/pix Orthophoto and (d) 4.9 mm/pix DEM; and Low-severity Shoving in (e) 2.5-mm/pix Orthophoto and (f) 4.9-mm/pix DEM

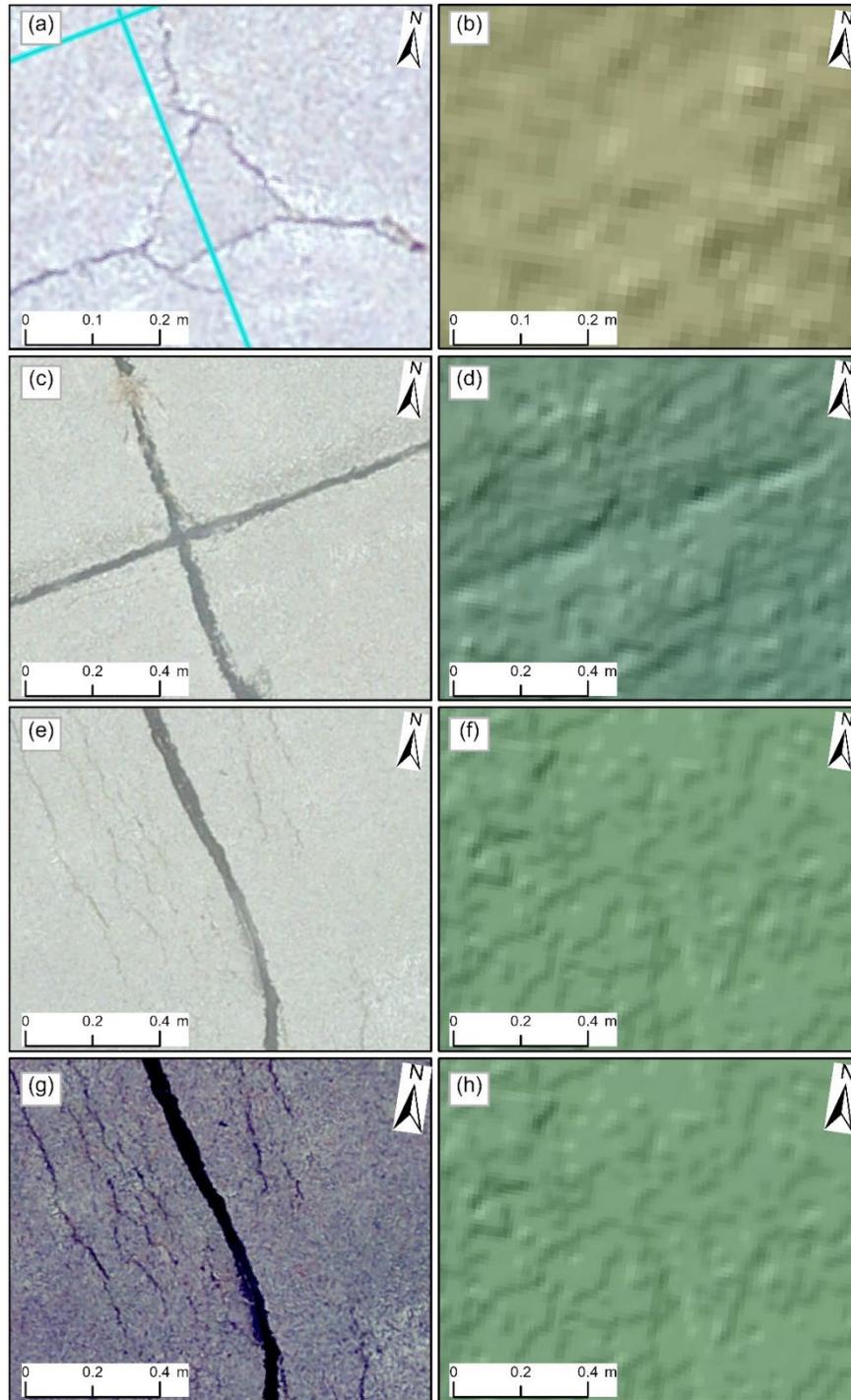


Figure 31. Low-severity L&T Cracks in (a) 3.6-mm/pix Orthophoto and (b) 14.3-mm/pix DEM; Medium-severity L&T Cracks in (c) 3.6-mm/pix Orthophoto and (d) 14.3-mm/pix DEM; Low-severity Shoving in (e) 3.6-mm/pix Orthophoto and (f) 14.3-mm/pix DEM; and High-severity L&T Cracks in (g) 2.5-mm/pix Orthophoto and (h) 4.9-mm/pix DEM

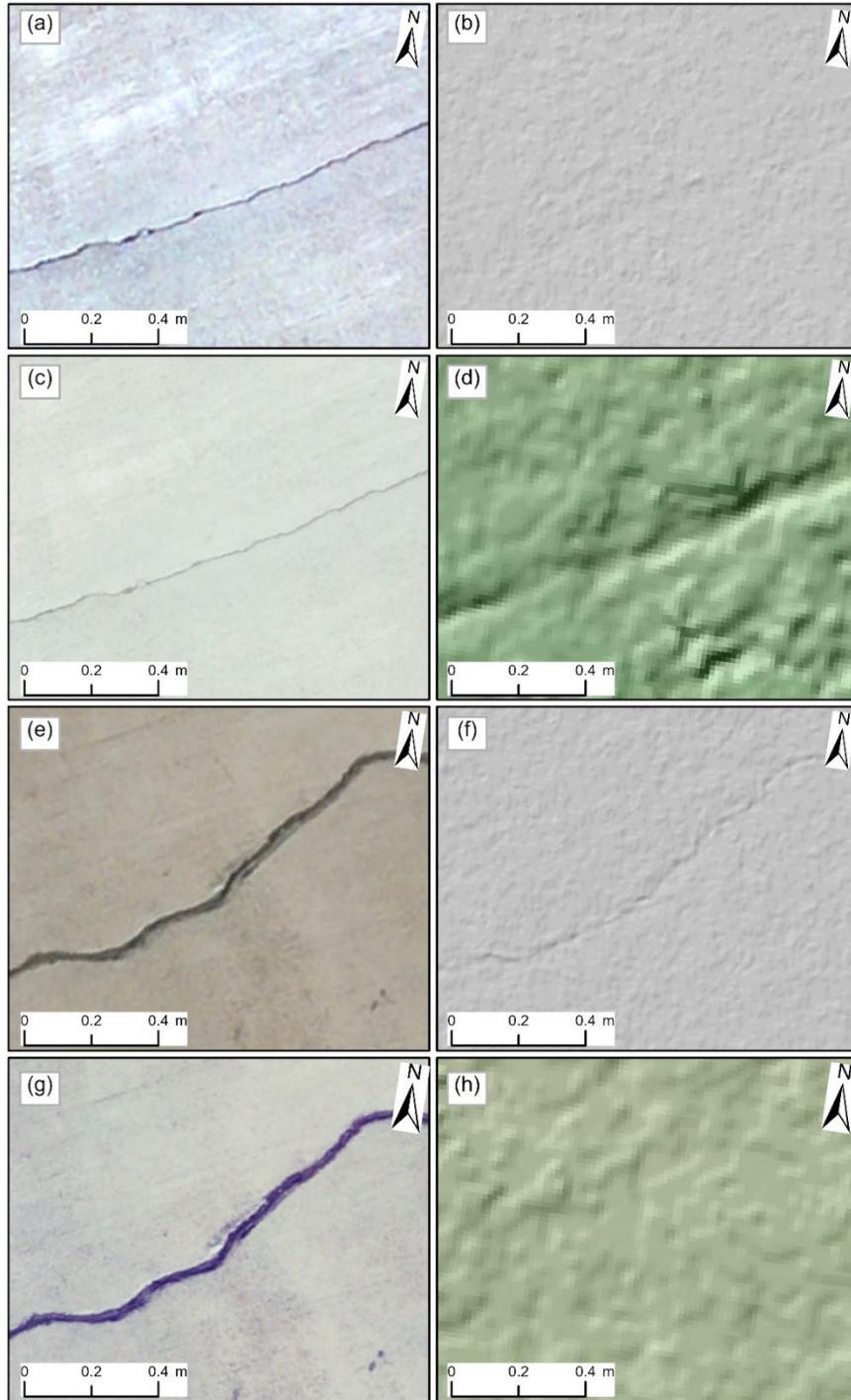


Figure 32. Low-severity LTD Cracks in (a) 2.5-mm/pix Orthophoto and (b) 4.9-mm/pix DEM, (c) 3.6-mm/pix Orthophoto and (d) 14.3-mm/pix DEM; and Medium-severity LTD Cracks in (e) 2.5-mm/pix Orthophoto, (f) 4.9-mm/pix DEM, (g) 2.5-mm/pix Orthophoto, and (h) 4.9-mm/pix DEM

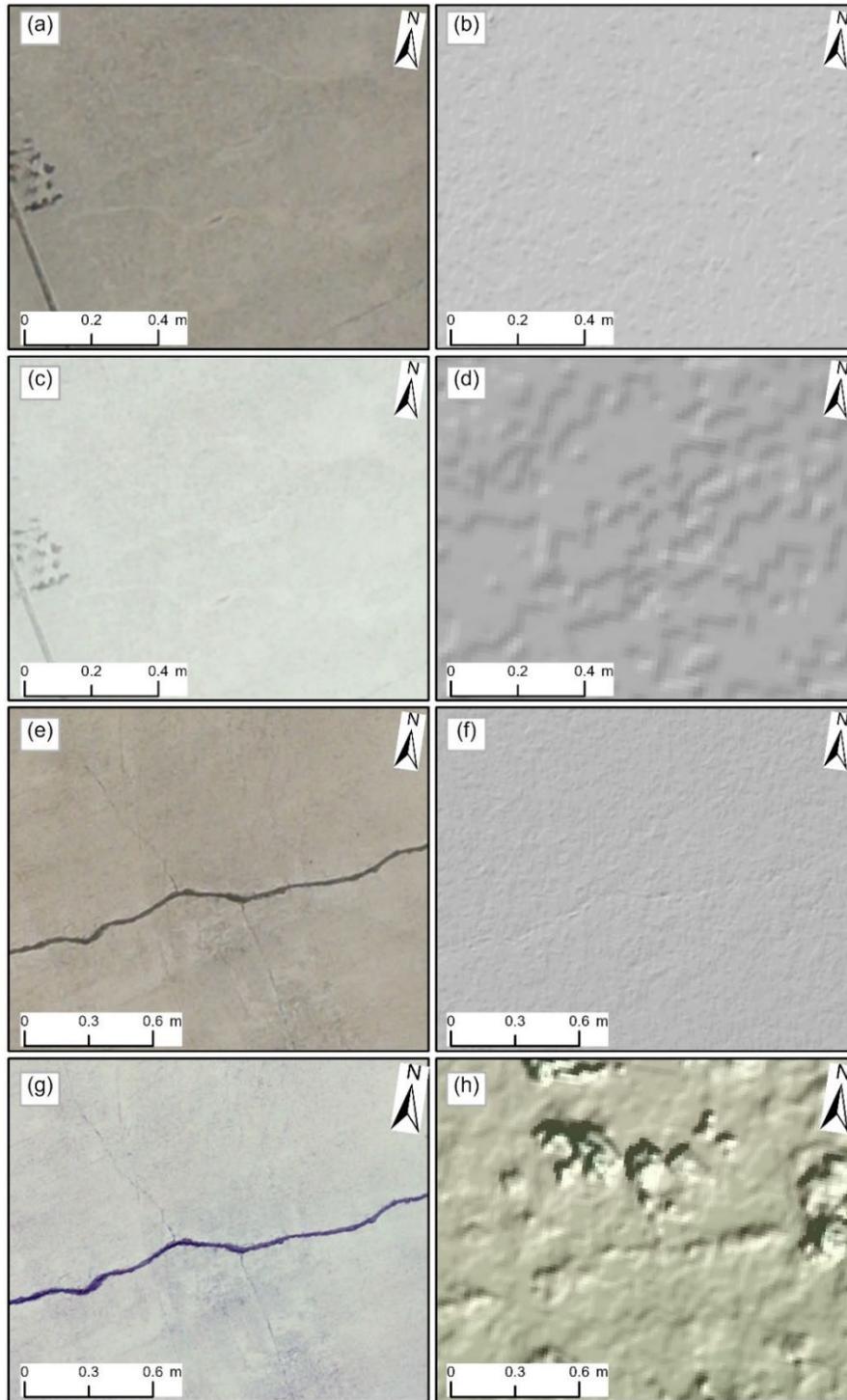


Figure 33. Low-severity Shrinkage Cracks in (a) 2.5-mm/pix Orthophoto and (b) 4.9-mm/pix DEM, (c) 3.6-mm/pix Orthophoto and (d) 14.3-mm/pix DEM; and Medium-severity Shattered Slab in (e) 2.5-mm/pix Orthophoto, (f) 4.9-mm/pix DEM, (g) 2.5-mm/pix Orthophoto, and (h) 4.9-mm/pix DEM

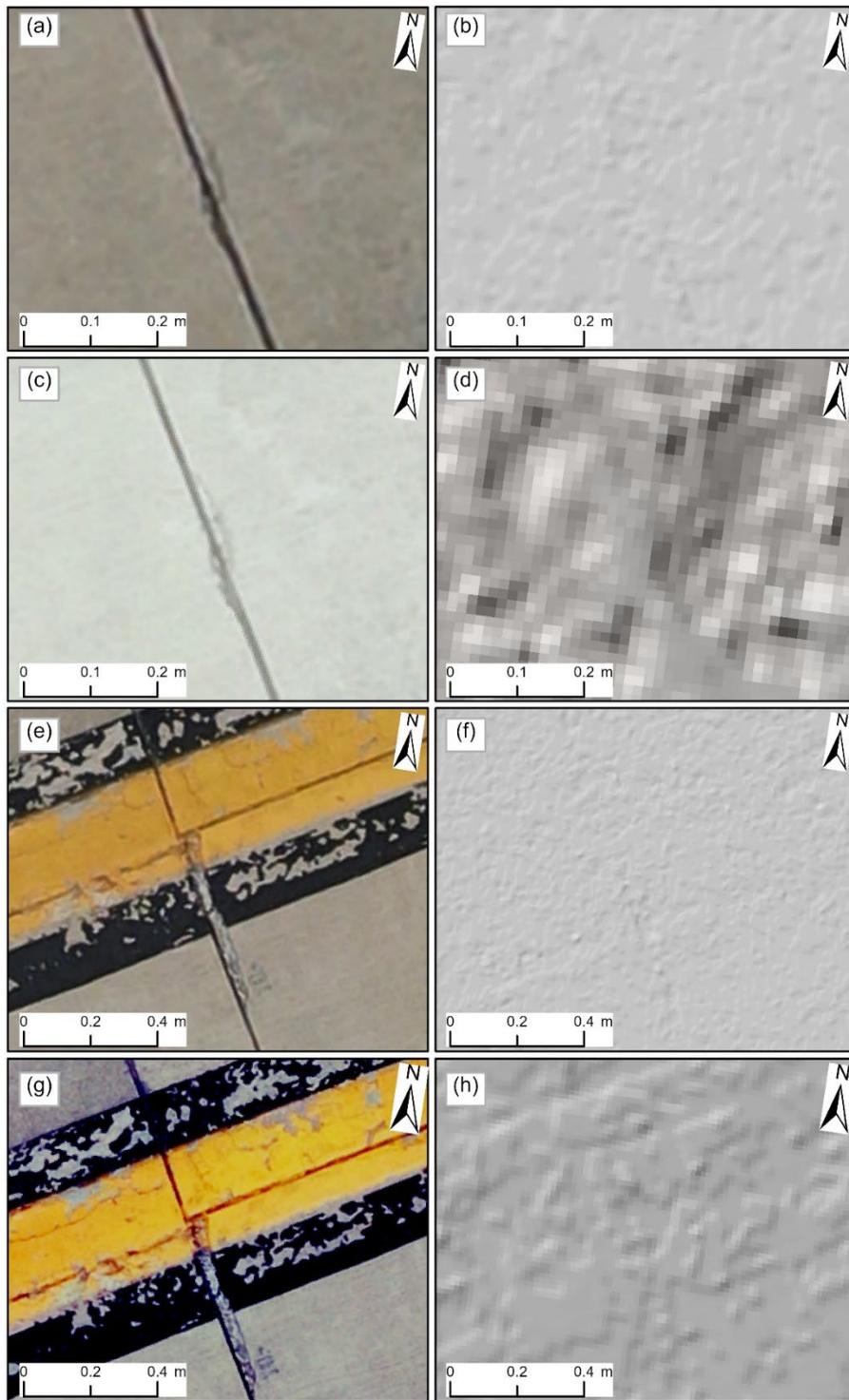


Figure 34. Low-severity Joint Spalling in (a) 2.5-mm/pix Orthophoto and (b) 4.9-mm/pix DEM, (c) 3.6-mm/pix Orthophoto and (d) 14.3-mm/pix DEM; and Medium-severity Joint Spalling in (e) 2.5-mm/pix Orthophoto, (f) 4.9-mm/pix DEM, (g) 2.5-mm/pix Orthophoto, and (h) 4.9-mm/pix DEM Derived

A part of the sUAS-based inspection results was uploaded to FAA PAVEAIR, which provided estimated PCI values as outputs (Federal Aviation Administration, 2021b). The sUAS-based PCI value and FOG PCI values were plotted in Figure 35. The results showed that the sUAS-based PCI values were relatively higher than FOG PCI values because of missing weathering and raveling. A sample unit on Taxiway D3 had a PCI value of 16, but the sUAS calculated PCI value was 57 because of missing medium-severity raveling on the whole sample unit.

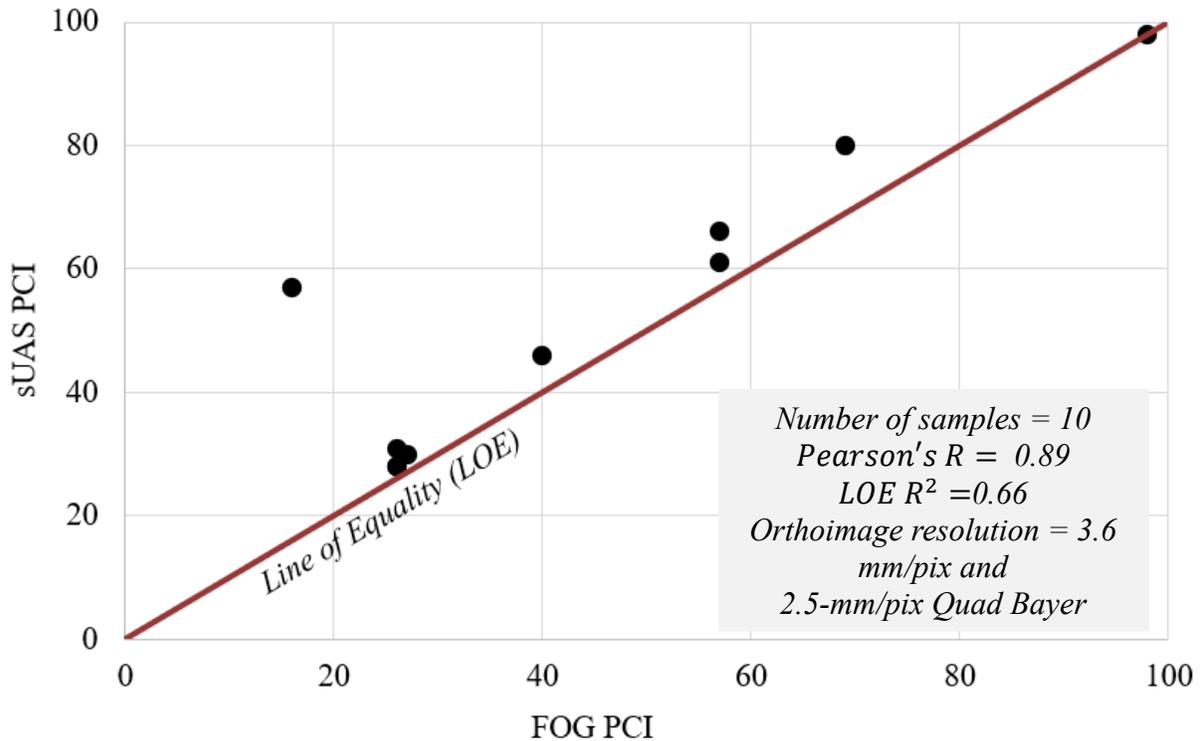


Figure 35. Foot-on-Ground PCI vs sUAS PCI Calculated Using 2.5- and 3.59-mm/pix Data of MTO

#### 4. FIELD DEMONSTRATION IN IOWA

##### 4.1 BOONE MUNICIPAL AIRPORT IN JUNE 2021

###### 4.1.1 Objectives

The research team collected sUAS data from Boone Municipal Airport (BNW), Boone, Iowa, on June 29, 2021. The condition of the runway and taxiway pavements at this airport is comparatively better, but the T-hangar pavement condition was rated poor in earlier PCI inspections. sUAS data collection at BNW had the following objectives:

- Collect sUAS data from the taxiway and runway pavements with a single sUAS system
- Evaluate the performance of the Mavic 2 Pro for complete data collection

- Evaluate the performance of available sUAS platforms and sensors for various distress visualization

#### 4.1.2 Field Demonstration in June 2021

The field demonstration plan developed for BNW was executed on June 29, 2021, for sUAS data collection. Eight team members, including four Part 107-certified sUAS pilots, took part in this data collection. The airport authority was contacted and met earlier to ensure efficient sUAS data collection. A NOTAM was issued as at the previous airports in Michigan and Illinois. FAA TPOC Matthew Brynick and Iowa State University communications specialist Mike Krapfl joined the data collection team. The data collection team followed the standard sUAS and airport safety guidelines as outlined in Appendices K and L.

The Mavic 2 Pro with 20 mp RGB optical camera was used for the complete data collection over Taxiway A and Runway 15/33. Optical RGB and stereo thermal images of the T-hangars were collected using the M2EA. As shown in Table 9, data were collected using three different sUAS systems: Bergen Hexacopter with 45.7-mp optical RGB Nikon D850 camera, Mavic 2 Pro with 20-mp optical camera, and M2EA with 48-mp Quad Bayer optical RGB and 640x512 thermal sensor. The focus of the data collection was on Runway 15/33, Taxiway A, T-hangar 1, T-hangar 2, and high-resolution sample units. The research team planned to collect sUAS data using MdMapper1000+ with Sony RX1R-II 42.4-mp optical RGB camera, but the system did not take off because of technical difficulties related to a recent software update.

Table 9. Summary of sUAS Data Collection at BNW

Target Area	sUAS Platforms	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
RW15BO-01 SU 01, 03, and 07	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	18.3	1.5	6.1
	M2EA	48-mp optical RGB	15.2	*2.4	9.5
	M2EA	512x640 thermal	24.4	31	N/A
Runway 15/33	Mavic 2 Pro	20-mp optical RGB	15.2	3.3	13.5
Taxiway 01	Mavic 2 Pro	20-mp optical RGB	15.2	3.3	13.5
	M2EA	48-mp optical RGB	15.2	*2.4	9.5
T-hangar 01 and T-hangar 02 Section 02	M2EA	48-mp optical RGB	15.2	*2.4	9.5
	M2EA	512x640 thermal	24.4	31	N/A

RW15BO-01 = Runway 15/33

\*2.4 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

Each photogrammetric stereo overlapping image datasets of the complete Runway 15/33, T-hangar 1, and T-hangar 2 of BNW collected with Mavic 2 Pro and M2EA were imported separately into Agisoft Metashape for processing. The locations of the sUAS images were corrected using the location information of 19 AeroPoints (with built-in GPS), along with 16 cloth GCPs placed

at different sections of the airfield whose location was recorded with a decimeter-accuracy Trimble GPS unit (). The images were processed on a desktop workstation to create optical RGB orthophotos and DEMs. The research team exported down-sampled orthophotos of the Runway 15/33, T-hangar 1, and T-hangar 2, and shared with the PCI data collection team. In addition, the orthophoto and DEM of Taxiway A were also generated. However, because of the long, narrow shape of the taxiway, which can cause quality issues with photogrammetry software, the orthophoto output contained unexpected spatial deviation resulting in poor-quality spatial positioning of some parts of Taxiway A. Therefore, another set of optical RGB optical data were collected from Taxiway A using M2EA on August 2, 2021. In this data collection, 10 AeroPoints were reused three times to increase the number of GCPs. The GCPs were placed at one section of the taxiway, sUAS data was collected, and the GCPs were moved to the next section. It was observed that 10 minutes of AeroPoints placement could provide centimeter-level GPS accuracy, although at least 30 minutes is the standard method in this research.

As was done at the other airports, APTech conducted an airfield pavement distress FOG survey using the ASTM D5340-20 standard at BNW. The two-person team traveled to Boone, Iowa, on August 4 and observed, rated, and recorded the airfield distresses onto a handheld, GPS-enabled tablet. The data were processed and the PCI values for all sample units and branches of the airfield pavement were calculated based on the ASTM D5340-20 standard. A set of selected sample units of Apron, Taxiway A, and Runway 15/33 were inspected. The PCI values for the Apron sample units were 86 and 87, whereas they ranged from 43 to 82 for Runway 15/33. The condition of the Taxiway A sample units was relatively better, and the PCI values were between 57 and 95. A total of 33 PCC sample units was inspected. The predominant airfield pavement distresses were corner breaks, LTD cracks, small patching, large patching, popouts, joint spalling, corner spalling, and ASR of different severities.



### 4.1.3 Results and Discussions

The sUAS data collection focused on the complete data collection from Taxiway A, Runway 15/33, and T-hangar 01 and T-hangar 02 at BNW. However, the PCI data were collected from Taxiway A, Runway 15/33, and a part of the Apron. There were 27 common sample units where both the sUAS data and PCI data were collected. The orthophotos of 2.5 mm/pix and 3.3 mm/pix generated using data collected using M2EA and Mavic 2 Pro over Taxiway A and Runway 15/33, respectively, at 15.2 m altitude were visually observed and quantified. The recorded data were used to calculate the PCI values for each sample unit and plotted against the FOG PCI results, as shown in Figure 37.

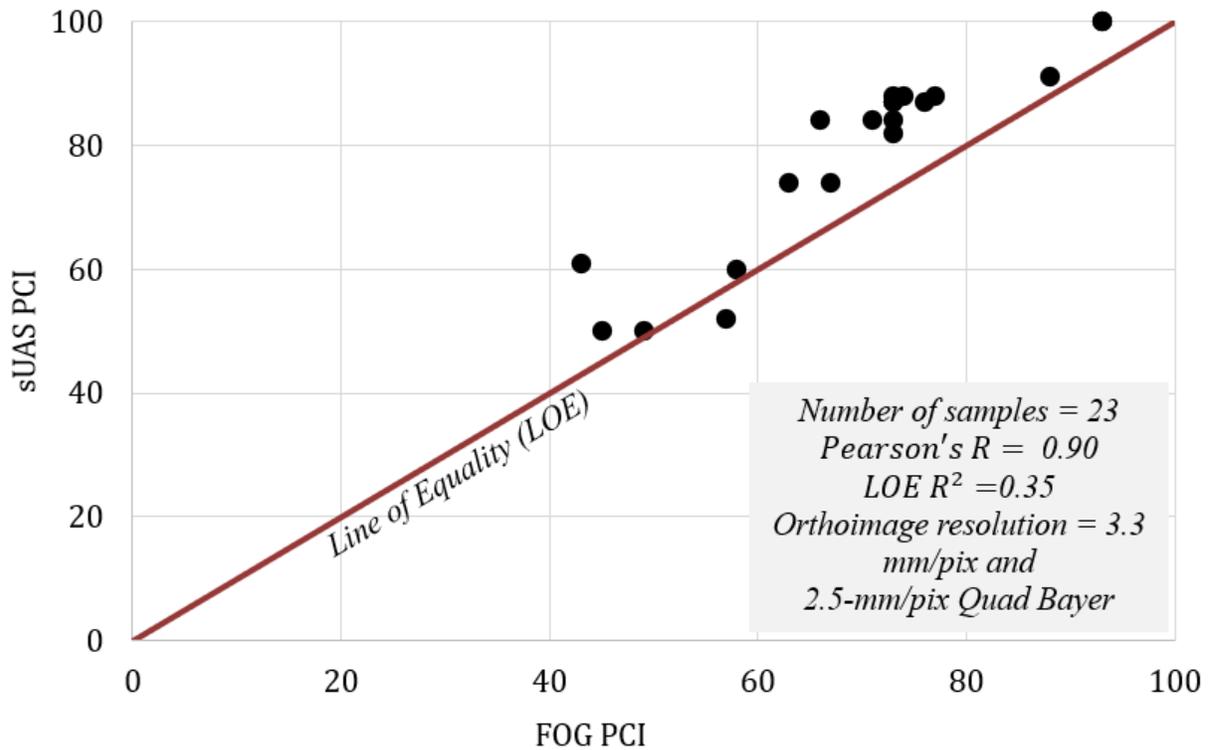


Figure 37. Foot-on-Ground PCI vs sUAS PCI Calculated Using 2.5-mm/pix and 3.3-mm/pix Data of BNW

The following results were summarized from the analysis:

- The analysis shows that the sUAS PCI values are somewhat higher than the FOG PCI. This can be explained, in part, by the difficulty in identifying low- and medium-severity ASR on sUAS image-based interpretation.
- The crack-based distresses (LTD cracks, corner break, corner spalling, and joint spalling) were detectable, and their associated severity was accurately measured in both 2.5-mm/pix and 3.3-mm/pix optical RGB data.

- Small and large patching of medium- and low-severity, and pop-outs, were clearly visible. Severity levels were accurately detected in all data regardless of their resolutions.
- Joint seal damage with high severity was detectable in 2.5 mm/pix, but medium severity was challenging to identify. The low-severity joint seal damage was completely unidentifiable.

The orthophoto, DEM, and hillshade of different resolutions were imported into ArcGIS Pro to study their capabilities in detecting and rating airfield pavement distresses. The PCI dataset collected by APTech through their manual survey was designated the ground truth data in this visual analysis. The comparison summary is presented in Table 10, and results are shown in Figures 38 through 49.

Table 10. Summary of the Findings of BNW

ASTM D5340 Distress	Severity	Resolution Tested (mm/pix)		Distress Detected in Highest Resolution (mm/pix)		Remarks
		RGB	DEM	RGB	DEM	
Corner break (62)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 38
	M	*2.4	9.5	3	ND	Figure 40
LTD cracks (63)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 39
	M	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 40
Joint seal damage (65)	L	3.3, *2.4	9.5, 13.5	ND	ND	
	M	*2.4	9.5	ND	ND	Figure 48
	H	*2.4	9.5	*2.4	9.5	Figure 41
Small patching (66)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 42
	M	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	6.1	Figure 43
Large patching (67)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	6.1	Figure 44
Pop-outs (68)		1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	6.1	Figure 45
Faulting (71)	L	*2.4	9.5	ND	ND	Figure 41
Shrinkage crack (73)	N/A	*2.4	9.5	ND	ND	Figure 41
Joint spalling (74)	L	3.3	13.5	3.3	ND	Figure 48
	M	3.3	13.5	3.3	ND	Figure 48
Corner spalling (75)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	ND	ND	Figure 46
	M	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 47
ASR (76)	L	1.5, 3.3, *2.4	6.1, 9.5, 13.5	ND	ND	
	M	1.5, 3.3, *2.4	6.1, 9.5, 13.5	3.3	ND	Figure 49

\*2.4-mm/pix data are excluded. 2.4 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

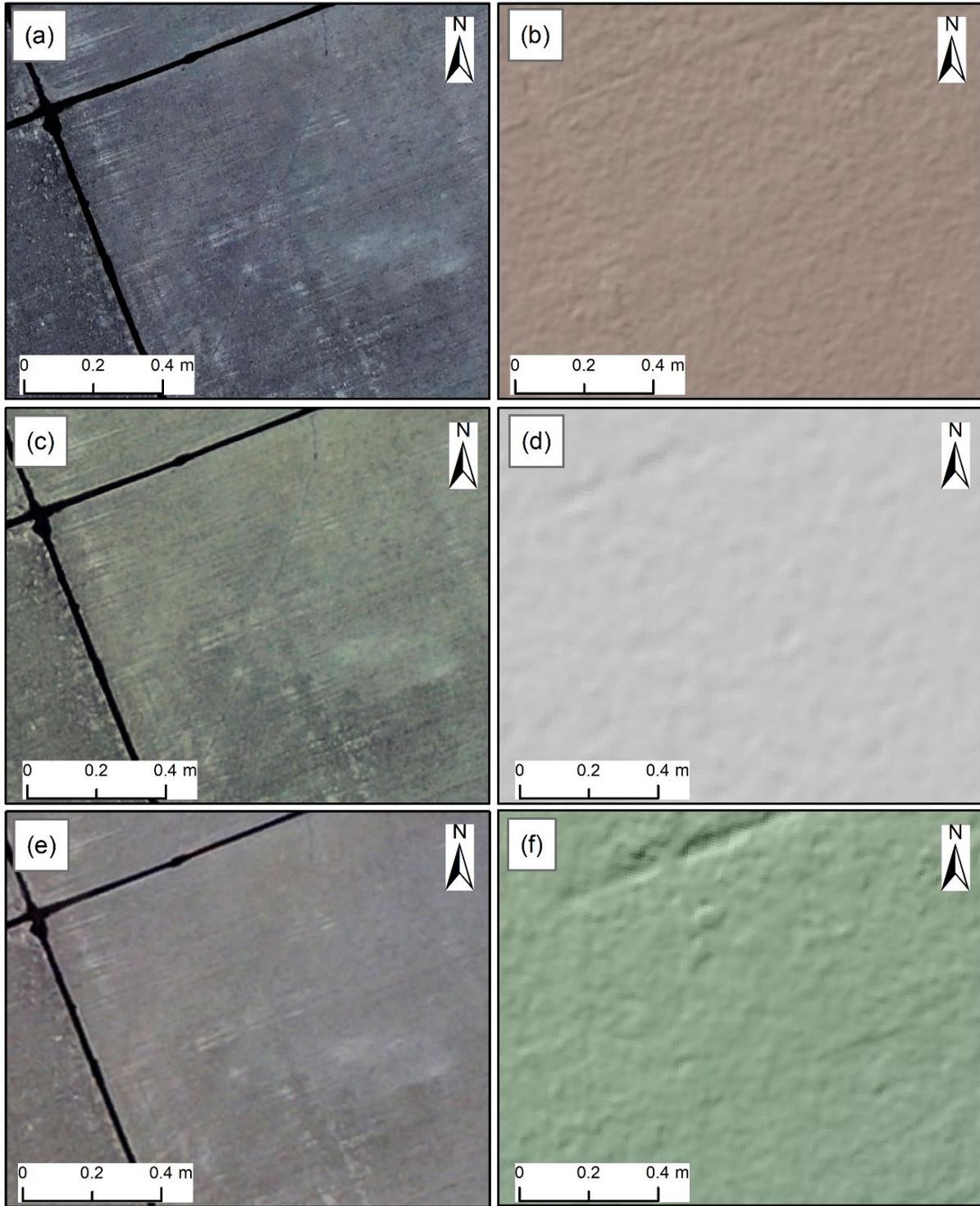


Figure 38. Low-severity Corner Break in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

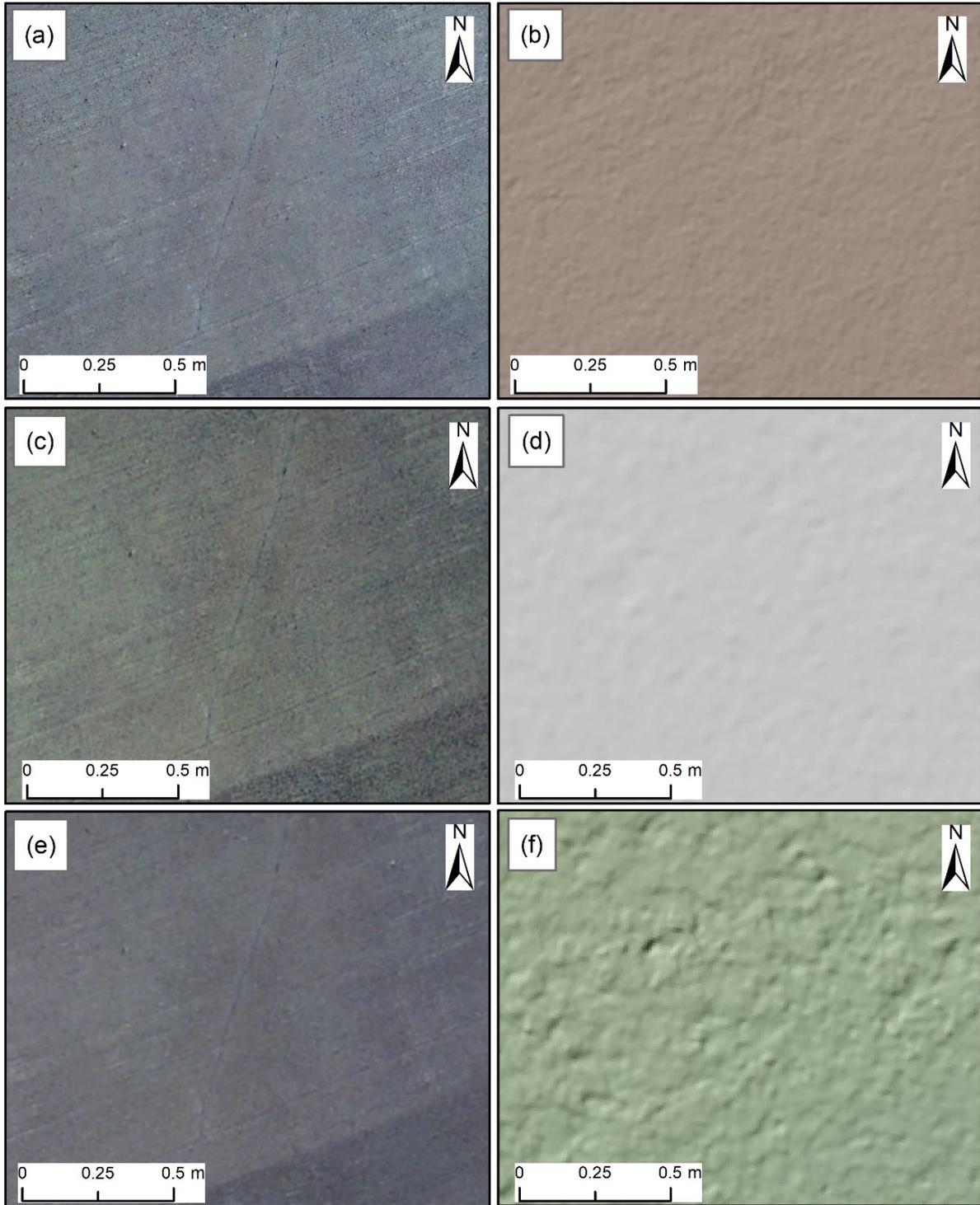


Figure 39. Low-severity LTD Cracks in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

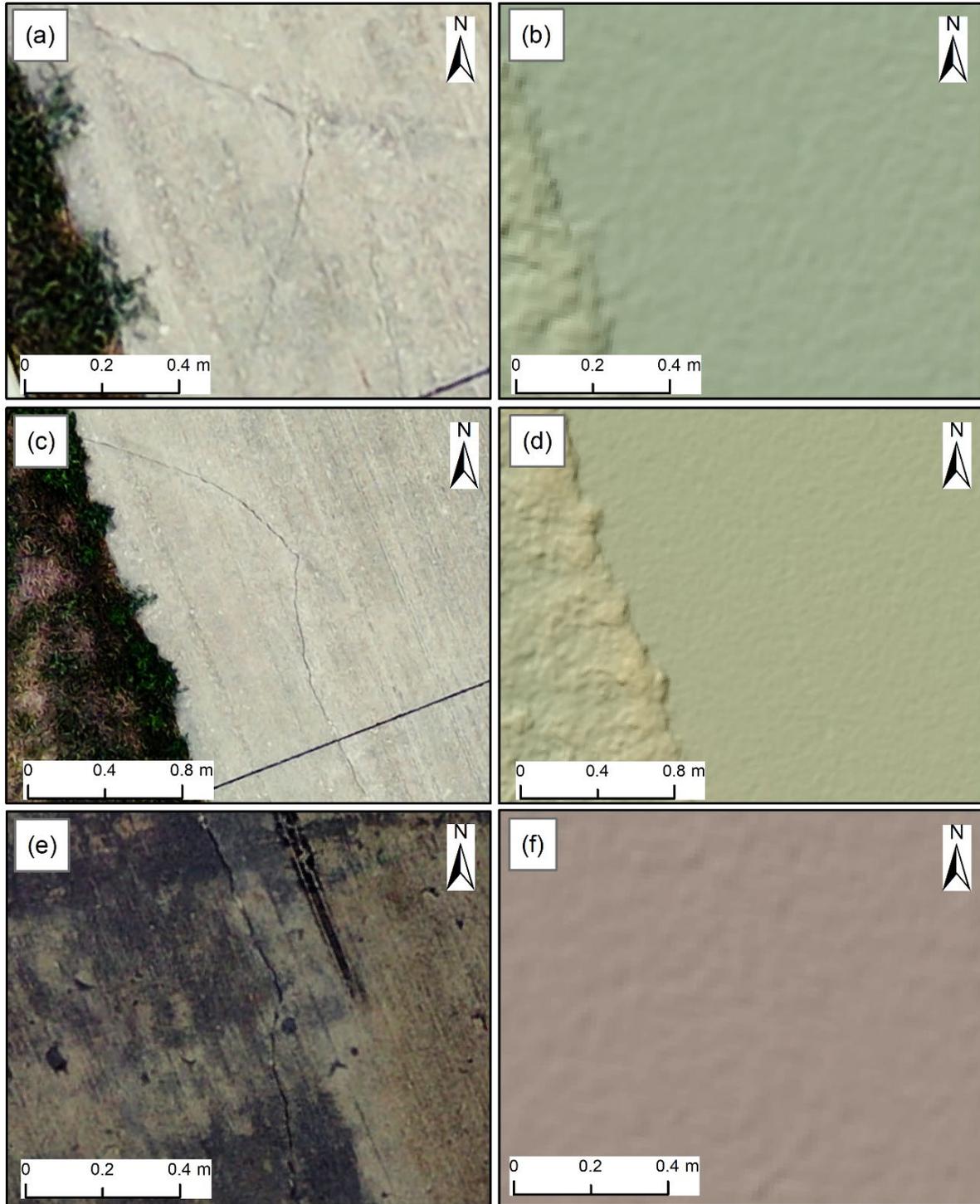


Figure 40. Medium-severity Corner Break in (a) 2.4-mm/pix Orthophoto and (b) 9.5-mm/pix DEM; and Medium-severity LTD cracks in (c) 2.4-mm/pix Orthophoto, (d) 9.5-mm/pix DEM, (e) 3.3-mm/pix Orthophoto, and (f) 13.5-mm/pix DEM

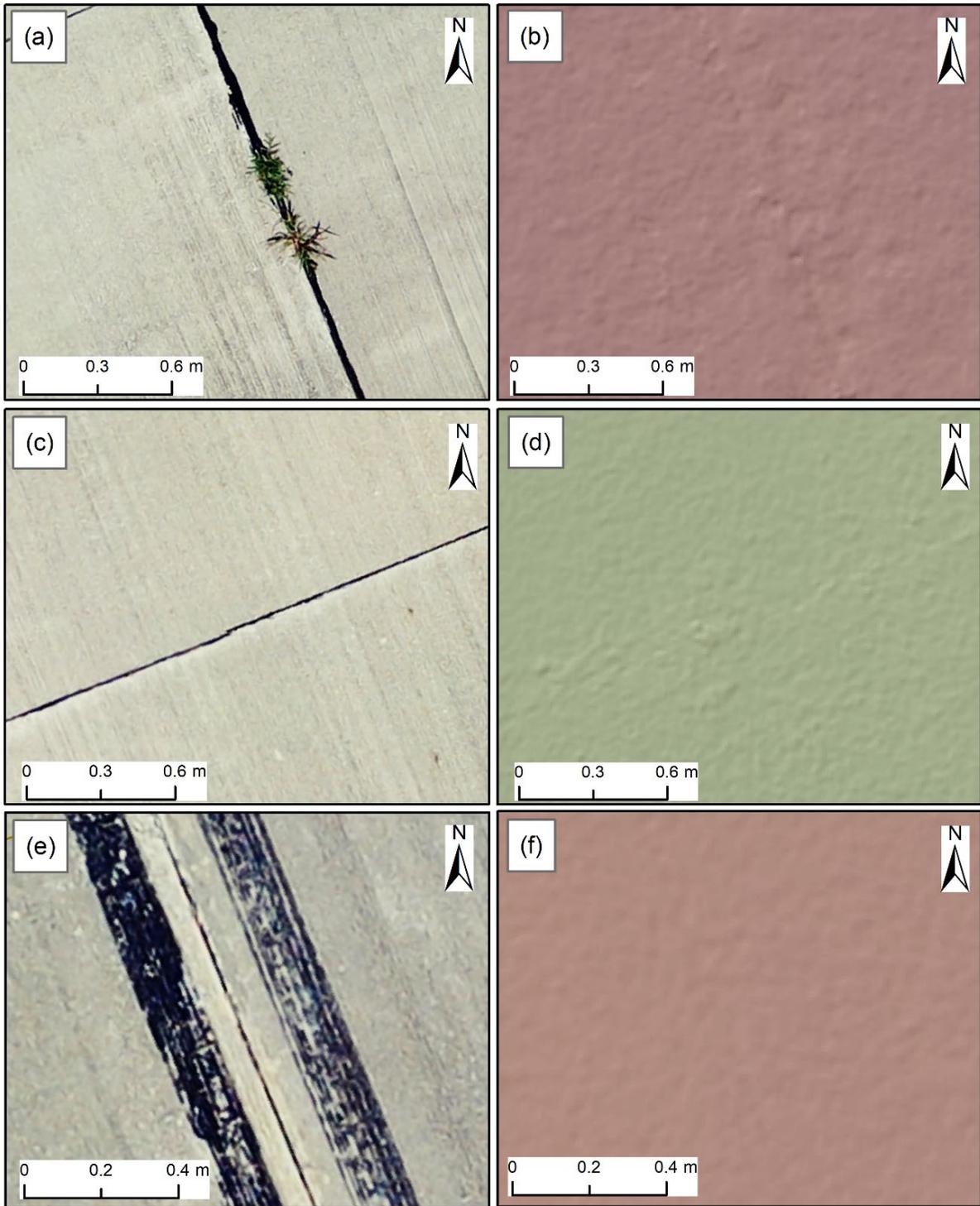


Figure 41. High-severity Joint Seal Damage in (a) 2.4-mm/pix Orthophoto and (b) 9.5-mm/pix DEM; and Low-severity Faulting in (c) 2.4-mm/pix Orthophoto and (d) 9.5-mm/pix DEM; and Shrinkage Cracking in (e) 2.4-mm/pix Orthophoto and (f) 9.5-mm/pix DEM

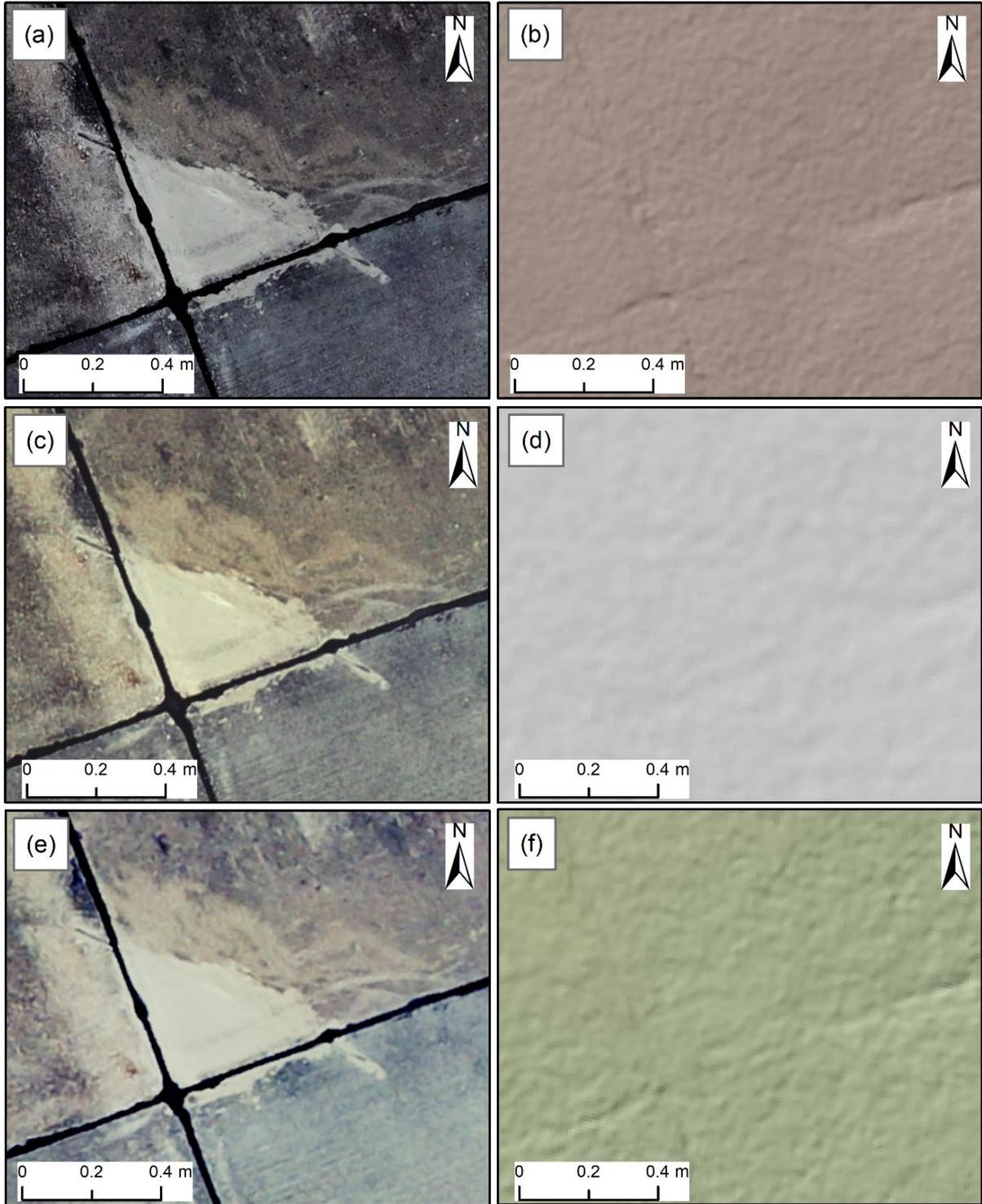


Figure 42. Low-severity Small Patching in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

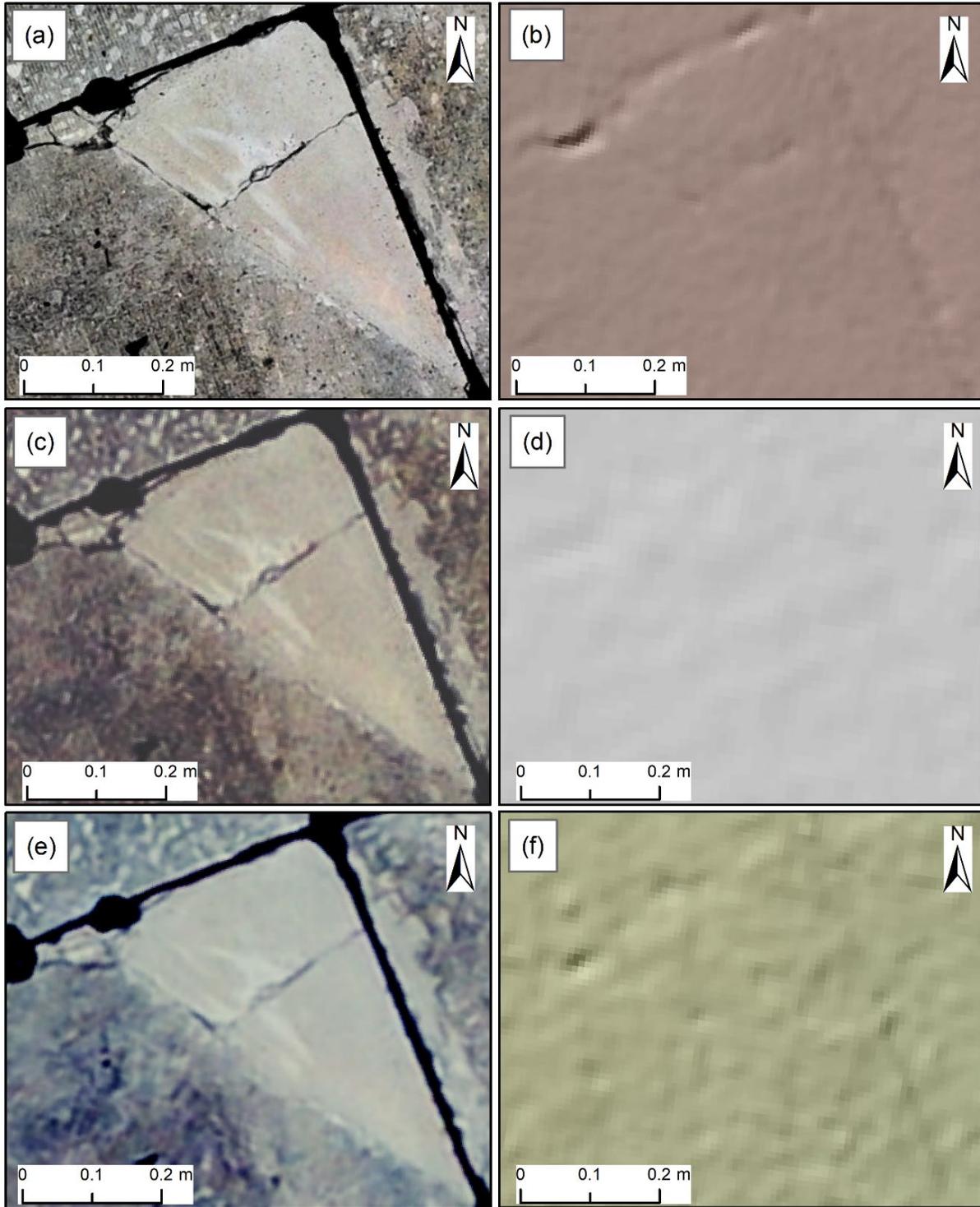


Figure 43. Medium-severity Small Patching in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

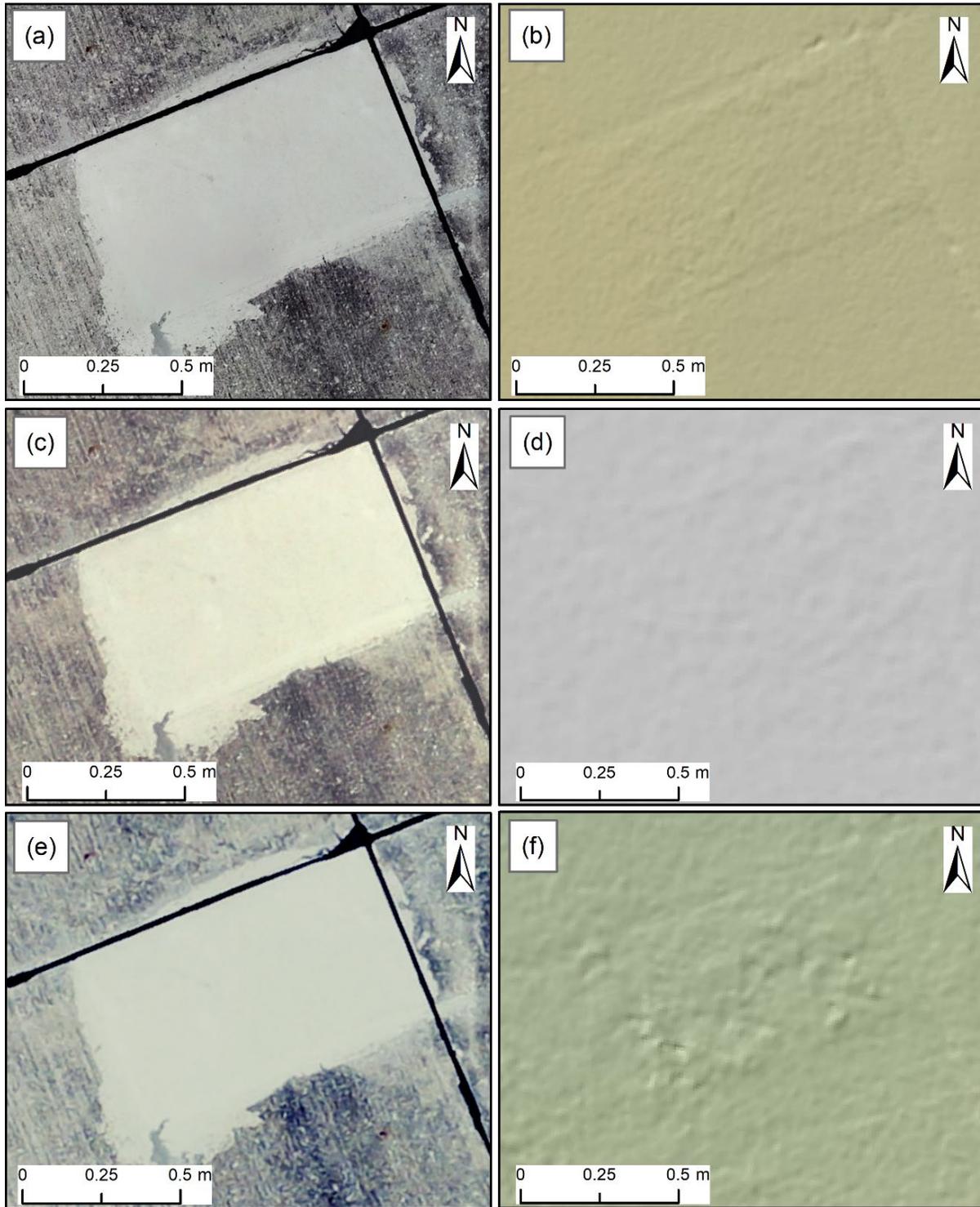


Figure 44. Low-severity Large Patching (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

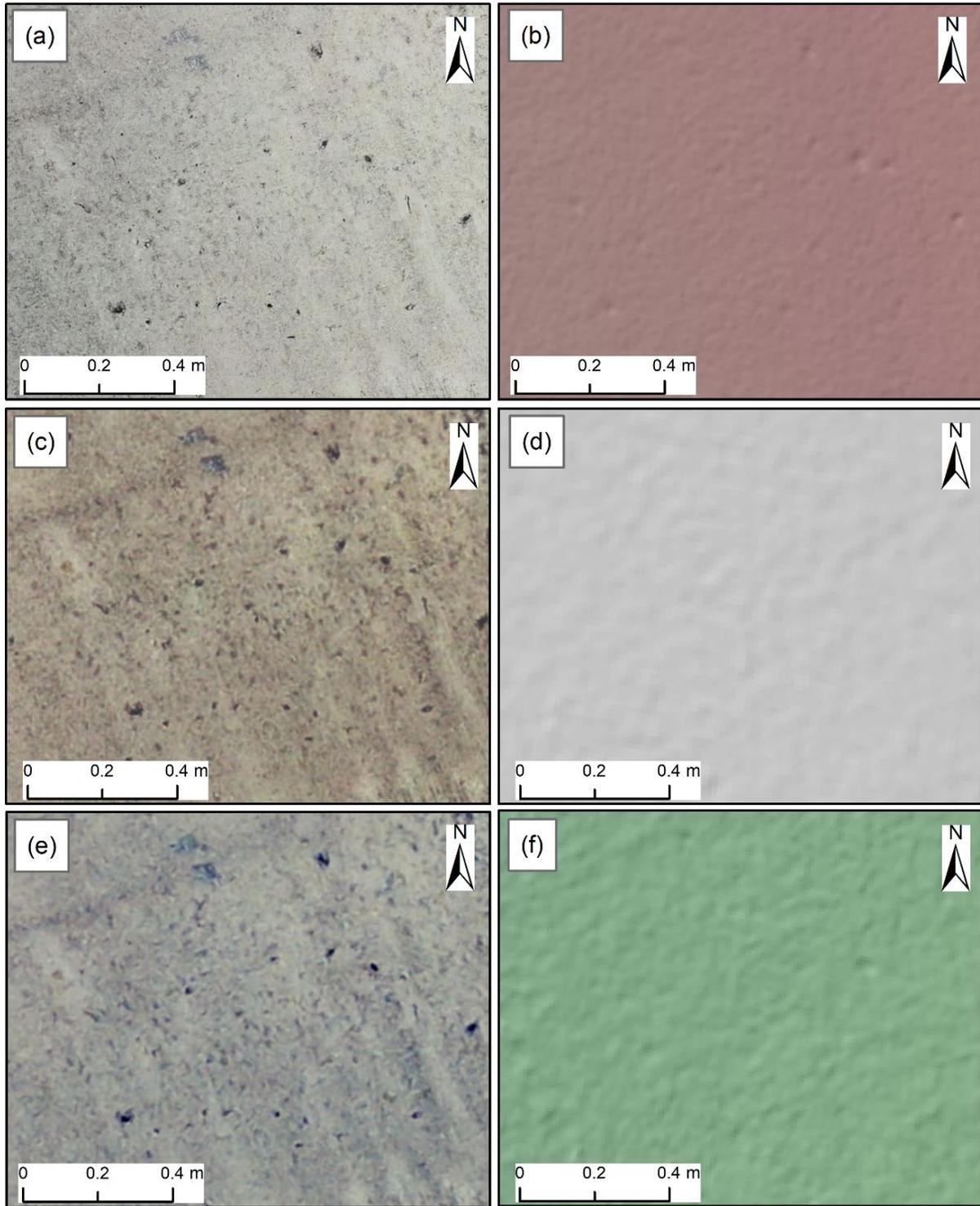


Figure 45. Pop-outs in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

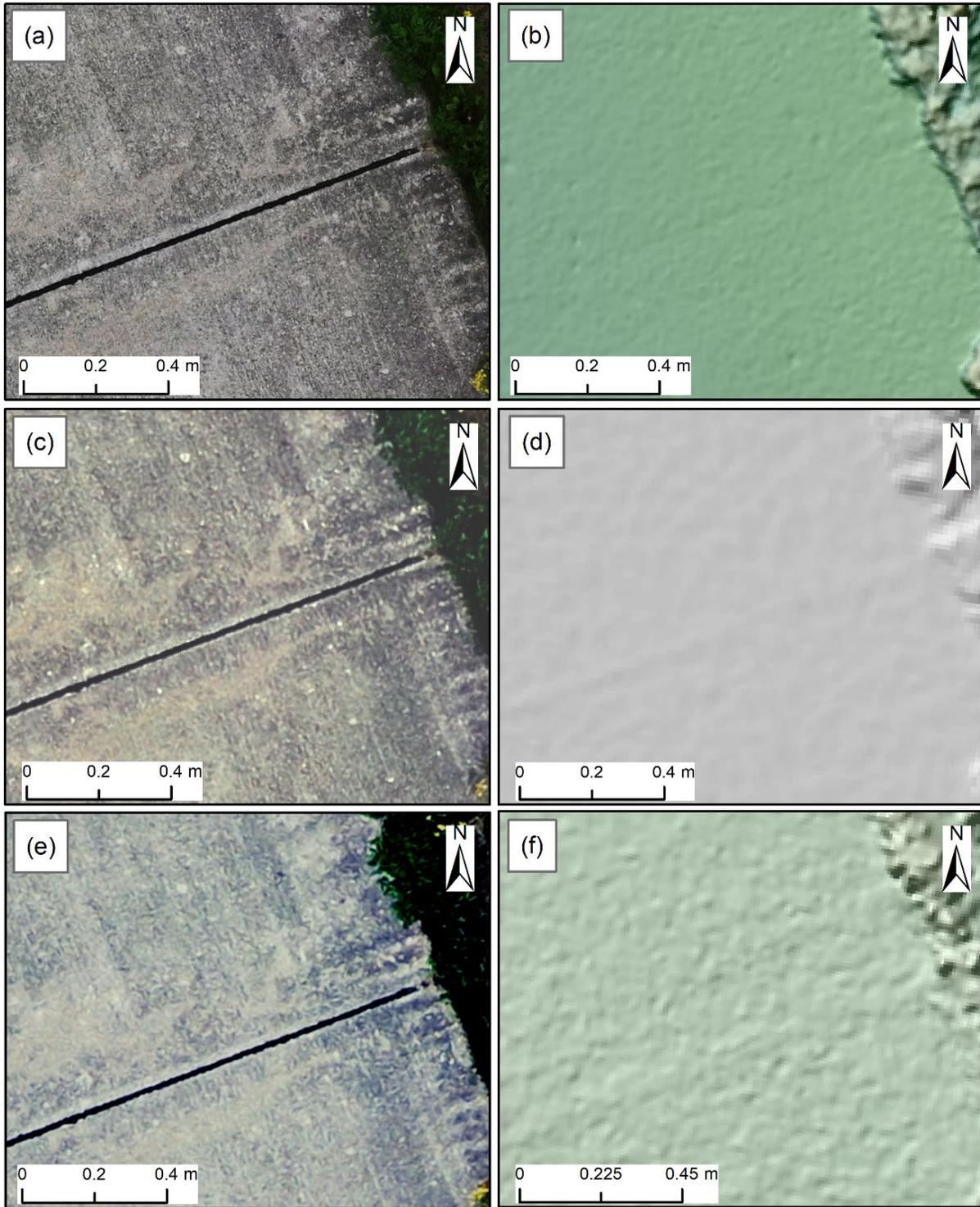


Figure 46. Low-severity Corner Spalling in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

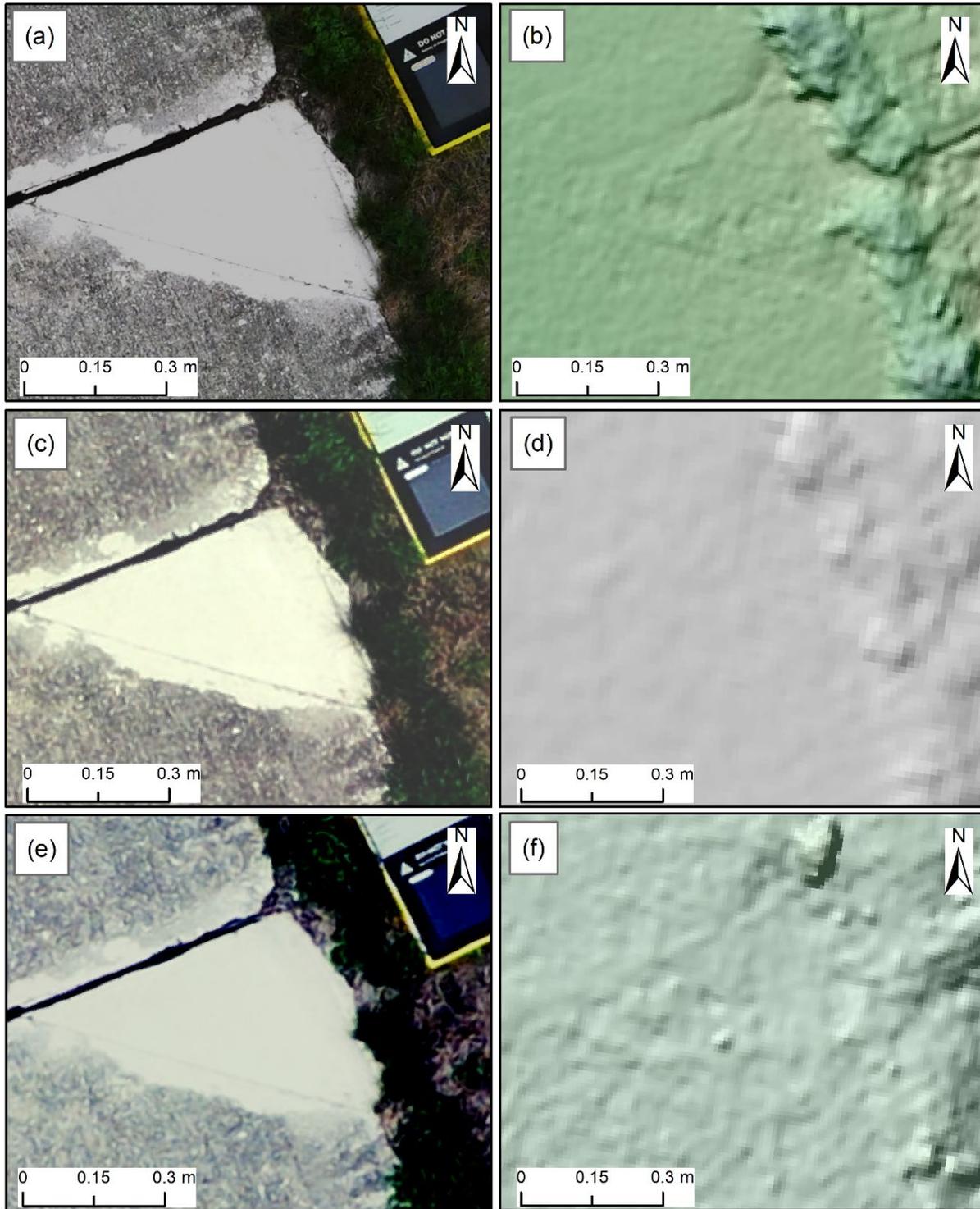


Figure 47. Low-severity Small Patching and Medium-severity Corner Spalling in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

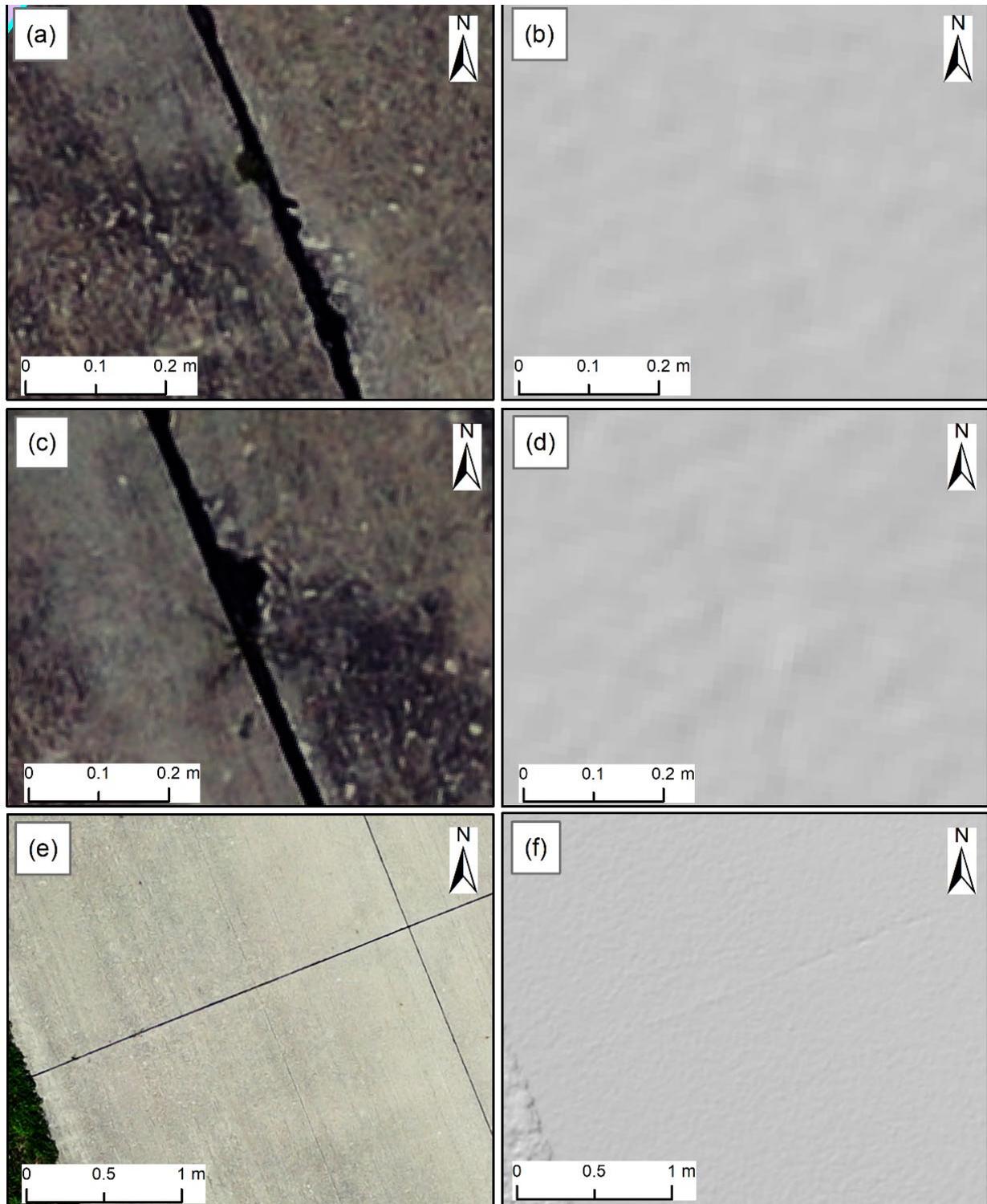


Figure 48. Low-severity Joint Spalling in (a) 3.3-mm/pix Orthophoto and (b) 13.5-mm/pix DEM; Medium-severity Joint Spalling in (c) 3.3-mm/pix Orthophoto and (d) 13.5-mm/pix DEM; and Medium-severity Joint Seal Damage in (e) 2.4-mm/pix Orthophoto and (f) 9.5-mm/pix DEM

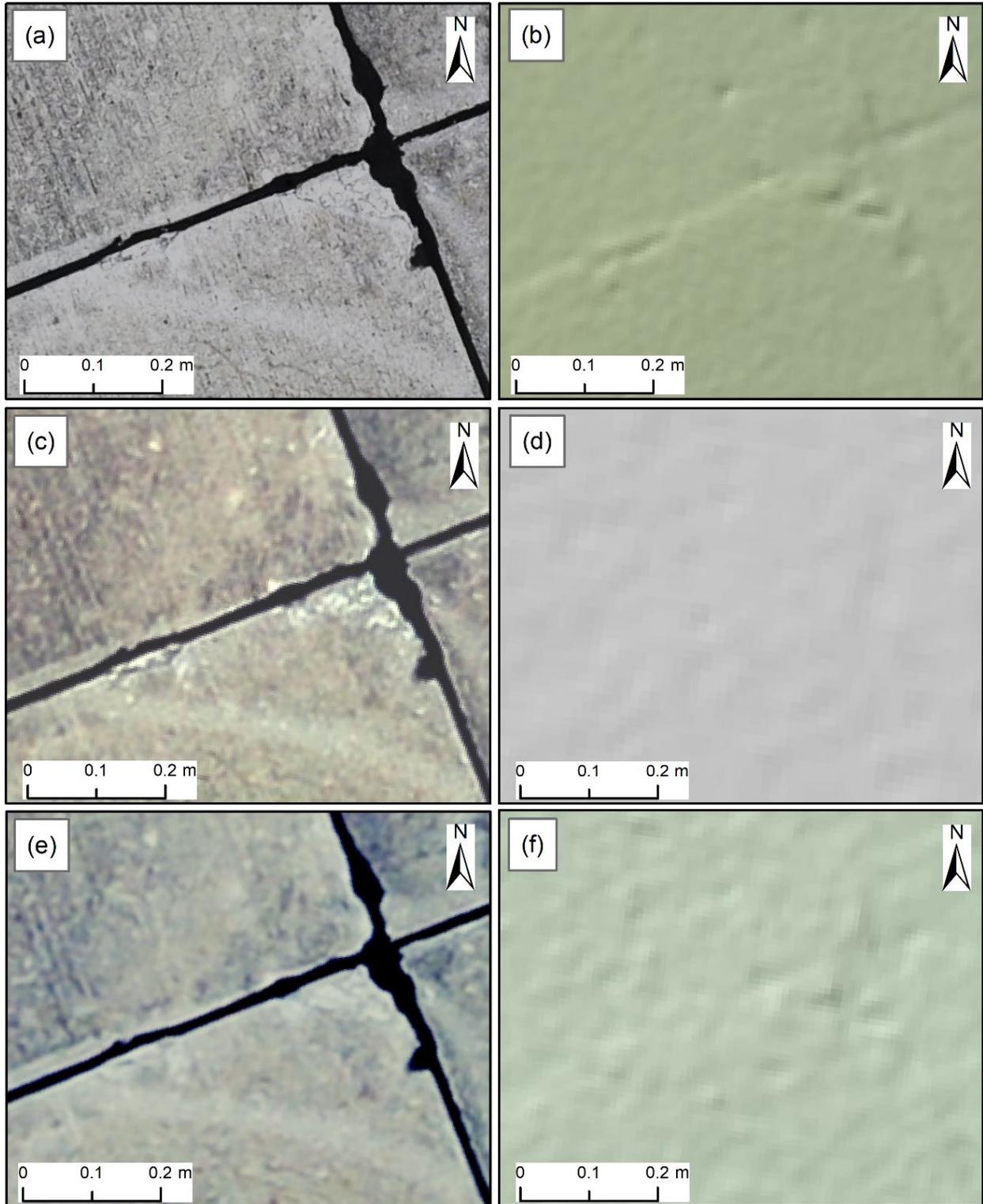


Figure 49. Medium-severity ASR in (a) 1.5-mm/pix Orthophoto, (b) 6.1-mm/pix DEM, (c) 3.3-mm/pix Orthophoto, (d) 13.5-mm/pix DEM, (e) 2.4-mm/pix Orthophoto, and (f) 9.5-mm/pix DEM

## 4.2 PERRY MUNICIPAL AIRPORT IN JUNE 2021

### 4.2.1 Objectives

The research team collected sUAS data from Perry Municipal Airport, Perry, Iowa (PRO), on June 30, 2021. The runway of PRO was in relatively poor condition compared to others included in this study, with numerous pavement distresses. Based on the lessons learned from ONZ, TTF, and MTO, the following objectives were determined for data collection at PRO:

- Collect sUAS data from focus areas of the airfield pavements with a single sUAS system
- Evaluate the performance of the Mavic 2 Pro for complete data collection (also part of the BNW effort completed the same week)
- Evaluate the performance of available sUAS platforms and sensors for visualization of various distresses

### 4.2.2 Field Demonstration in June 2021

On June 30, 2021, the research team collected sUAS data from PRO by following the sUAS data collection plan developed beforehand (Appendices M and N). Eight team members with four Part 107-certified sUAS pilots took part in this data collection. The same set of sUAS systems used at BNW were also used at PRO. Runway 14/32, Taxiway A, Apron Section 03, and high-resolution sample units were the focus of the data collection. The details of the sUAS platform, sensors, and types of data are shown in Table 11. The data collected from Runway 14/32 and Taxiway A and Apron of PRO were separately imported and processed in Agisoft Metashape. The locations of the sUAS images were corrected using the location information of 19 AeroPoints (with built-in GPS) and six cloth GCPs placed throughout the airfield at strategic points likely to result in well-positioned orthophoto output, as shown in Figure 50.

Table 11. Summary of sUAS Data Collection at BNW

Target Areas	sUAS Platforms	Sensors	AGL (m)	Resolution (mm/pix)	
				Orthophoto	DEM
RW14PR-02 SU 01, 04, and 08	Bergen Hexacopter	45.7 mp optical RGB Nikon D850	18.3	1.5	6
	M2EA	48 mp optical RGB	15.2	*2.5	10
	M2EA	512x640 thermal	24.4	31	N/A
Runway 14/32	Mavic 2 Pro	20 mp optical RGB	15.2	3.2	12.9
Taxiway 01	Mavic 2 Pro	20 mp optical RGB	15.2	3.2	12.9
Apron 01 Section 03	M2EA	48 mp optical RGB	15.2	*2.5	10
	M2EA	512x640 thermal	24.4	31	N/A

RW14PR-02 = Runway 14/32

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

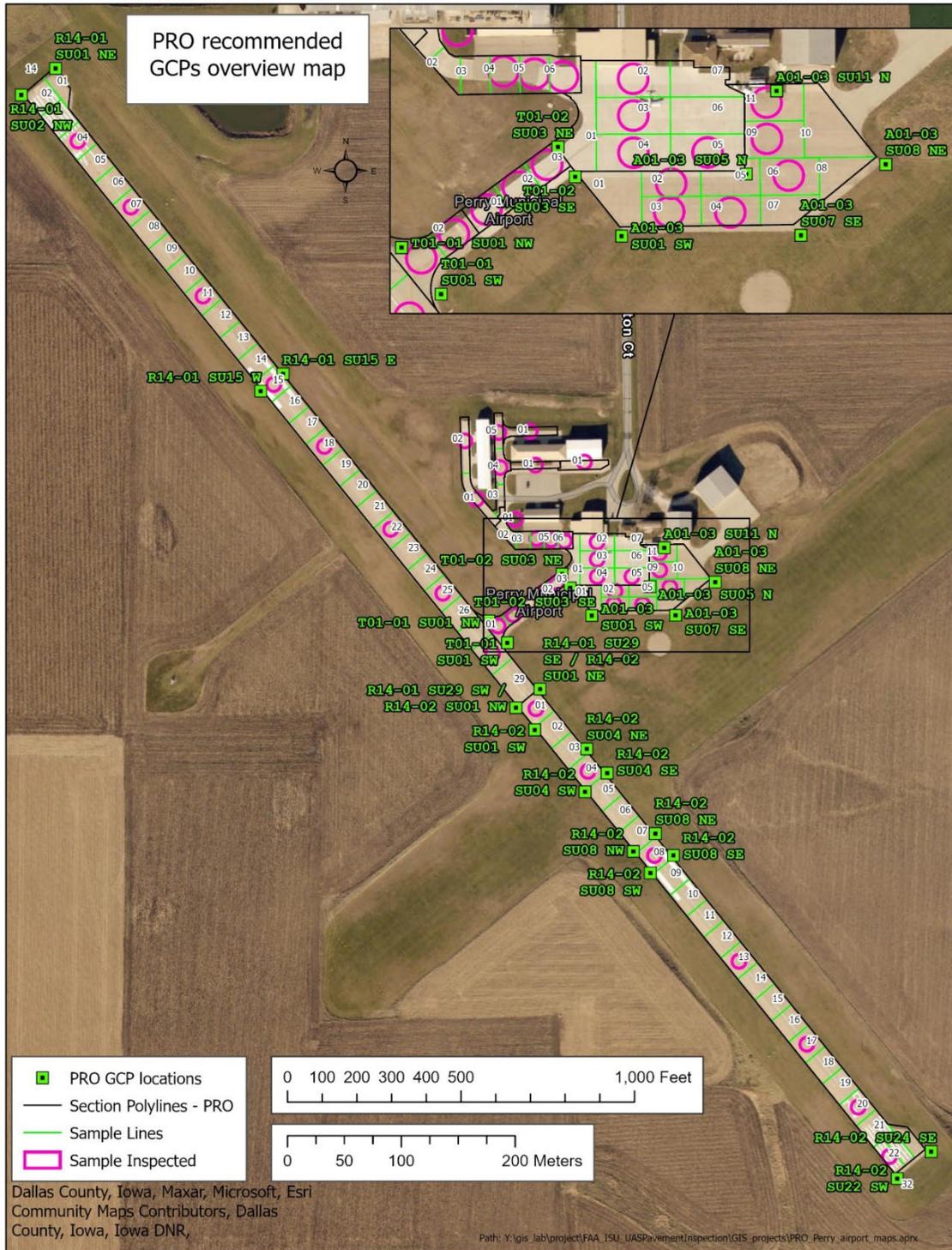


Figure 50. Recommended Locations for GCPs at PRO

The images were processed on a desktop workstation to create optical RGB orthophotos and DEMs. Because Taxiway A is very short, it was processed with Runway 14/32. The down-sampled

orthophotos of Runway 14/32, Taxiway A, and Apron were exported and shared with the PCI data collection team.

APTech conducted an airfield pavement distress FOG survey at PRO using ASTM D5340-20 standard and recorded the airfield distresses on a GPS-enabled tablet on August 3, 2021. The data were processed, and the PCI values for all sample units and branches of the airfield pavement were calculated based on the ASTM D5340-20 standard. Six sample units of Apron, two sample units of Taxiway A, and eight sample units of Runway 14/32 Section 01 were inspected. The PCI values for Apron sample units varied from 3 to 20, whereas it ranged from 14 to 51 on Runway 14/32. The condition of the Taxiway A sample units was relatively better, and the PCI values were 57 for both the inspected sample units. The predominant airfield distresses were corner break, LTD cracks, joint seal damage, small patching, large patching, faulting, shattered slab, shrinkage cracking, joint spalling, corner spalling, and ASR.

#### 4.2.3 Results and Discussions

The data collected from PRO on June 2021 were separately imported in Agisoft Metashape and processed to create RGB optical orthophoto and DEM. The M2EA and Mavic 2 Pro orthophoto data, both RGB orthophoto and DEM, collected at 15.2 m altitude, were compared against the PCI data collected by APTech. The comparisons are shown in Figure 51 through Figure 64 and summarized in Table 12. No PCI data were collected from the Runway 14/32 Section 02, where sample units were located. Therefore, the 1.5 mm/pix RGB orthophoto and 6 mm/pix DEM results are also excluded from this data analysis. The analysis of the available data has been provided below:

- 2.5- and 3.2-mm/pix RGB orthophoto data were adequate to detect corner breaks, LTD cracks, joint seal damage, small patching, large patching, faulting, shattered slab shrinkage crack, joint spalling, corner spalling, and ASR with different severity.
- 10-mm/pix DEM could be used for high-severity shattered slab and corner spalling. However, better resolution DEM generated using data collected with Nikon D850 has already proven very useful for distress detection in other airports.

Table 12. Summary of the Findings of PRO

ASTM D5340 Distress	Severity	Resolution Tested		Distress Detected and Severity Rating		Remarks
		RGB	DEM	RGB	DEM	
Corner break (62)	L	*2.5, 3.2	10, 12.9	3.2	ND	Figure 51
	M	3.2	12.9	3.2	ND	Figure 52
	H	3.2	12.9	3.2	ND	
LTD cracks (63)	L	*2.5, 3.2	10, 12.9	3.2	ND	Figure 52
	M	*2.5, 3.2	10, 12.9	3.2	ND	Figure 53
Joint seal damage (65)	L	*2.5	10	ND	ND	
	M	*2.5	10	*2.5	ND	
	H	3.2	12.9	3.2	ND	Figure 53
Small patching (66)	L	*2.5	10	*2.5	ND	Figure 55
	M	3.2	12.9	3.2	ND	
	H	3.2	12.9	3.2	12.9	
Large patching (67)	L	3.2	12.9	3.2	ND	Figure 56
Faulting (71)	L	*2.5, 3.2	10, 12.9	ND	ND	Figure 56
	M	3.2	12.9	ND	ND	
	H	3.2	12.9	ND	ND	
Shattered slab (72)	M	*2.5, 3.2	10, 12.9	ND	ND	
	H	*2.5	10	*2.5	10	
Shrinkage crack (73)	N/A	*2.5, 3.2	10, 12.9	3.2	ND	Figure 59
Joint spalling (74)	L	*2.5, 3.2	10, 12.9	3.2	ND	Figure 61
	M	*2.5, 3.2	10, 12.9	3.2	**12.9	
	H	*2.5, 3.2	10, 12.9	3.2	**12.9	
Corner spalling (75)	L	*2.5, 3.2	10, 12.9	3.2	ND	Figure 63
	M	*2.5, 3.2	10, 12.9	3.2	**12.9	
	H	*2.5, 3.2	10, 12.9	3.2	12.9	
ASR (76)	L	*2.5, 3.2	10, 12.9	3.2	ND	Figure 63
	M	*2.5, 3.2	10, 12.9	3.2	ND	
	H	*2.5, 3.2	10, 12.9	3.2	**12.9	

\*2.5 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

\*\*12.9 mm/pix only

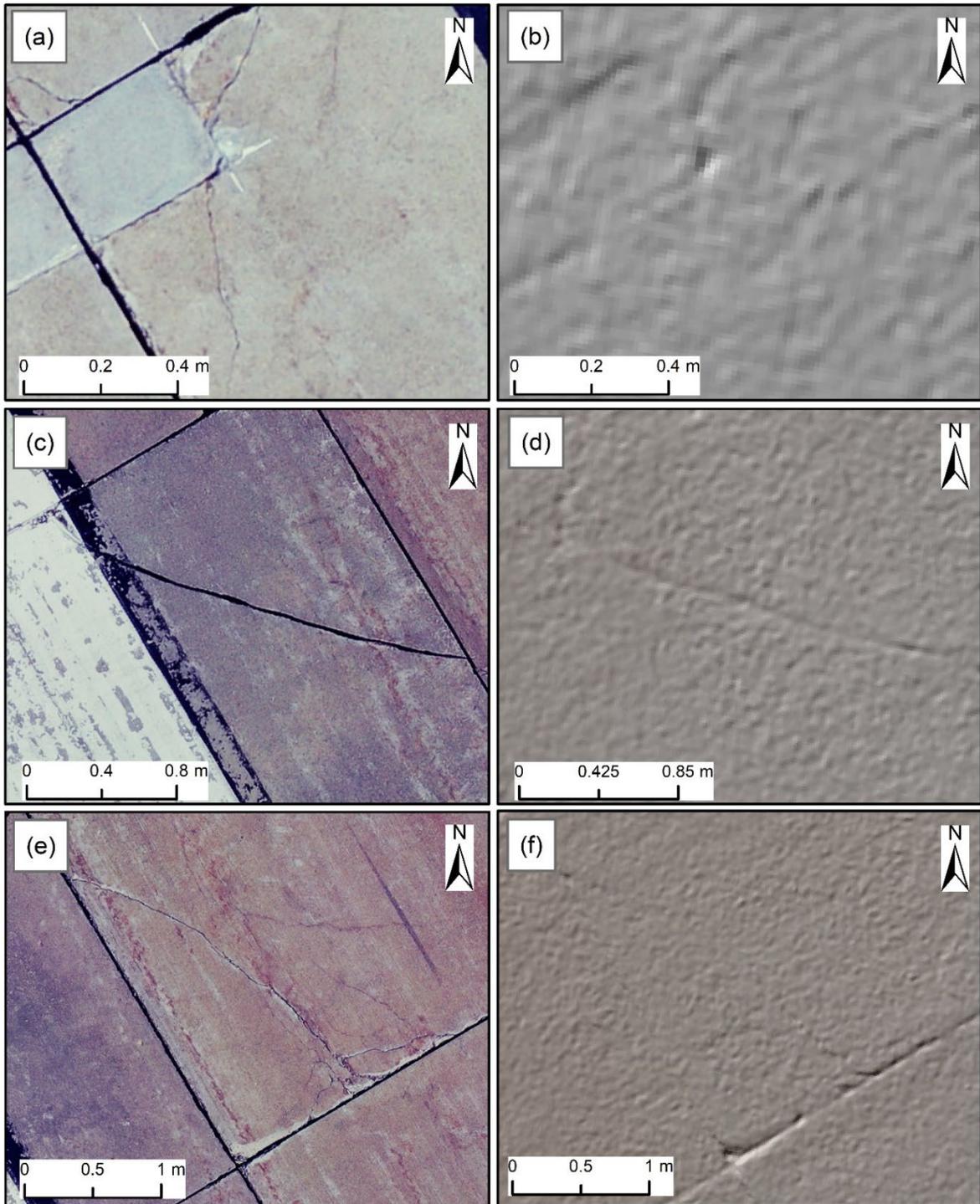


Figure 51. Low-severity Corner Breaks in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Medium-severity Corner Breaks (c) 3.2-mm/pix Orthophoto and (d) 12.9 mm/pix DEM; and High-severity Corner Breaks in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

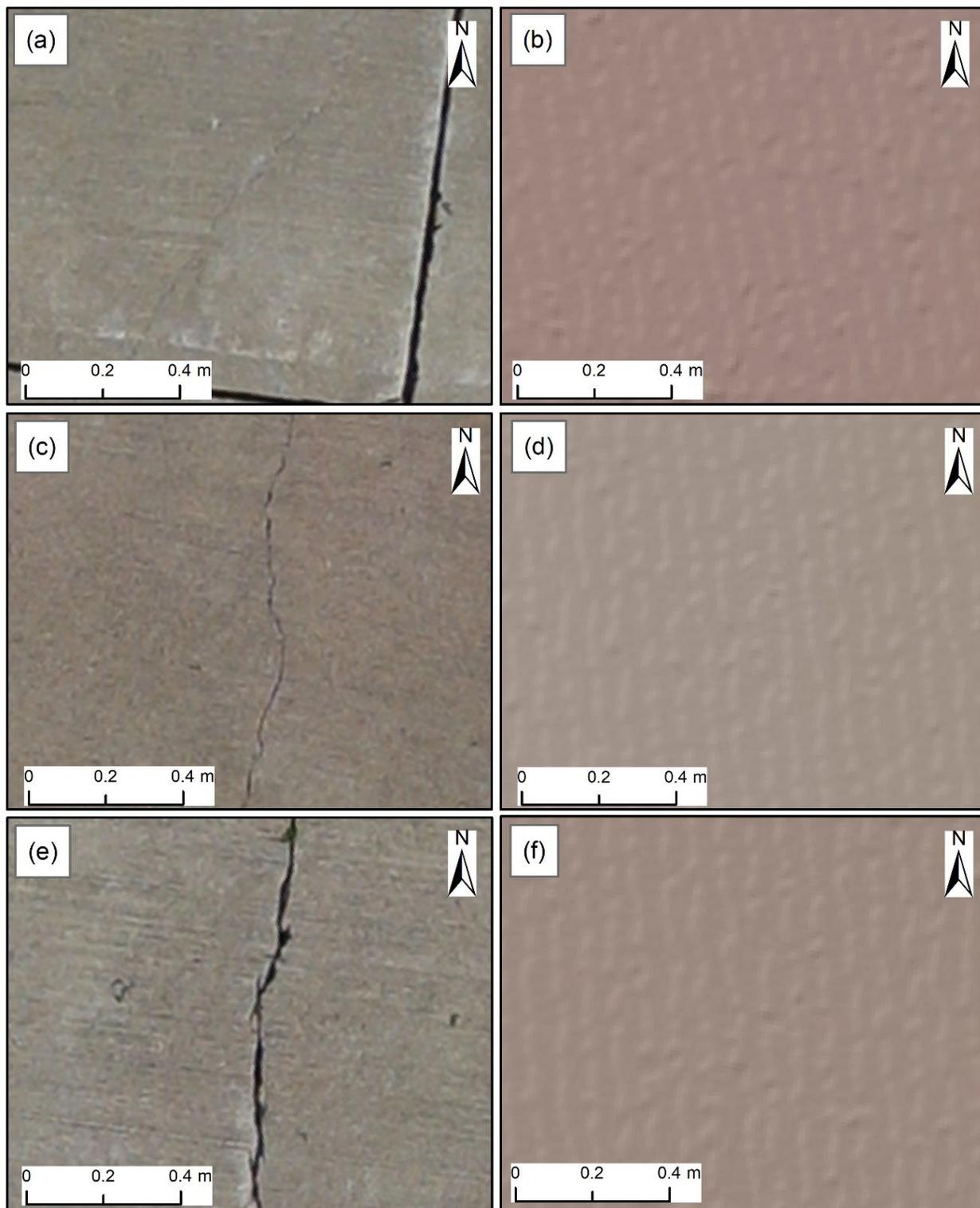


Figure 52. Low-severity Corner Break in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM;  
 Low-severity LTD Cracks in (c) 2.5-mm/pix Orthophoto, (d) 10-mm/pix DEM;  
 and Medium-severity LTD Cracks in 2.5-mm/pix Orthophoto and (f) 10 mm/pix DEM

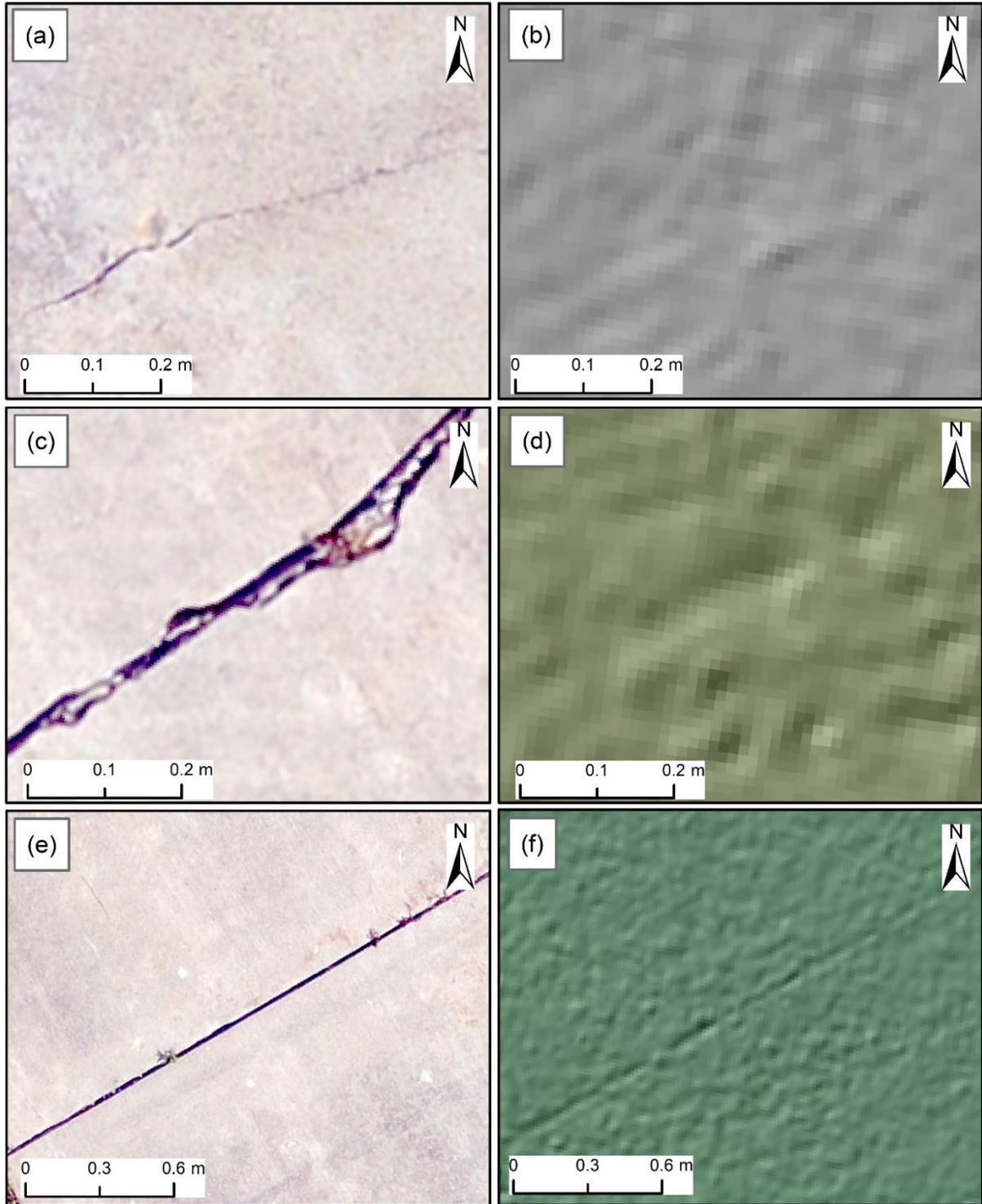


Figure 53. Low-severity LTD Cracks in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Medium-severity LTD Cracks in (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and High-severity Joint Seal Damage in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

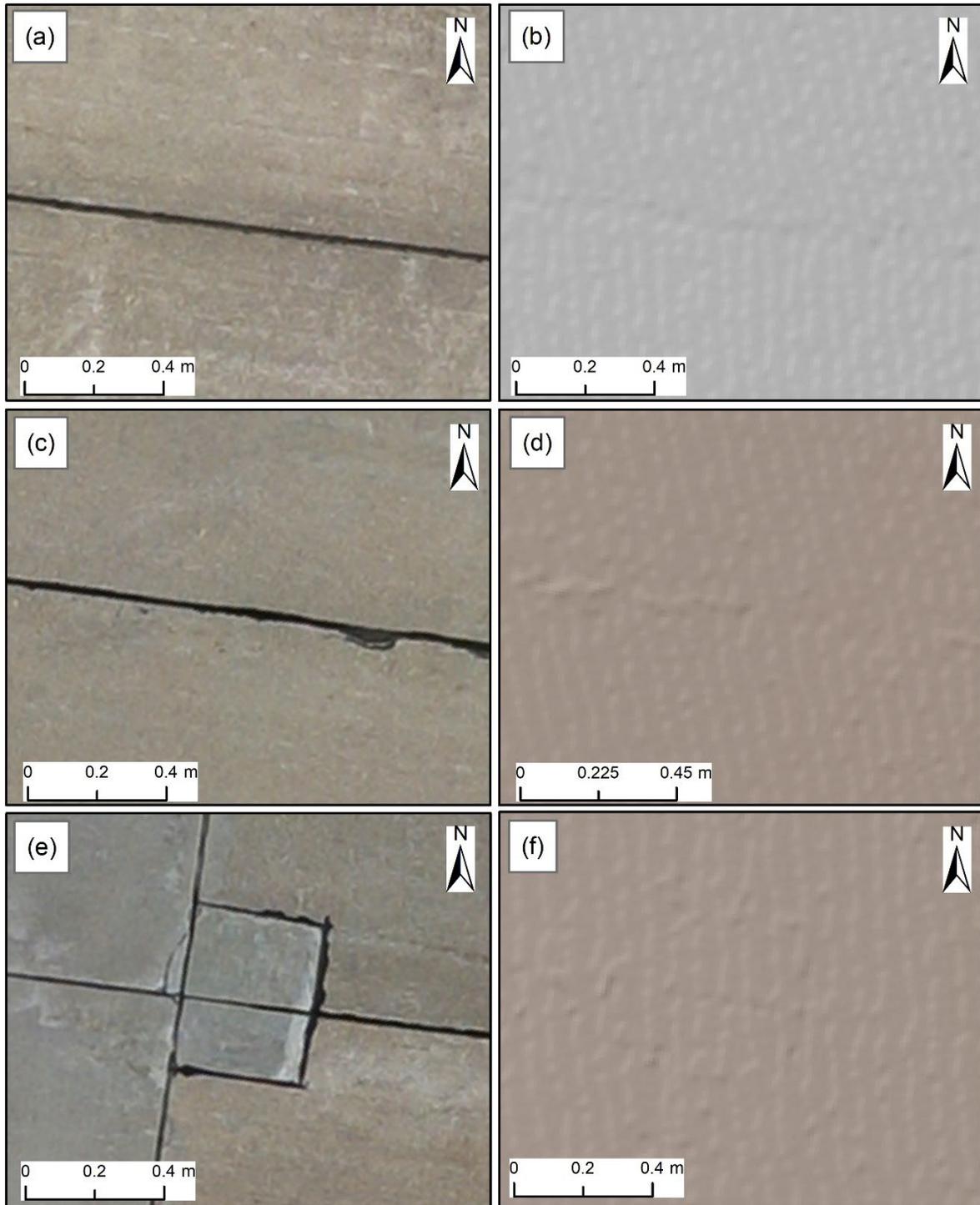


Figure 54. Low-severity Joint Seal Damage in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM; Medium-severity Joint Seal Damage in (c) 2.5-mm/pix Orthophoto and (d) 10-mm/pix DEM; and Low-severity Small Patching in (e) 2.5-mm/pix Orthophoto and (f) 10-mm/pix DEM

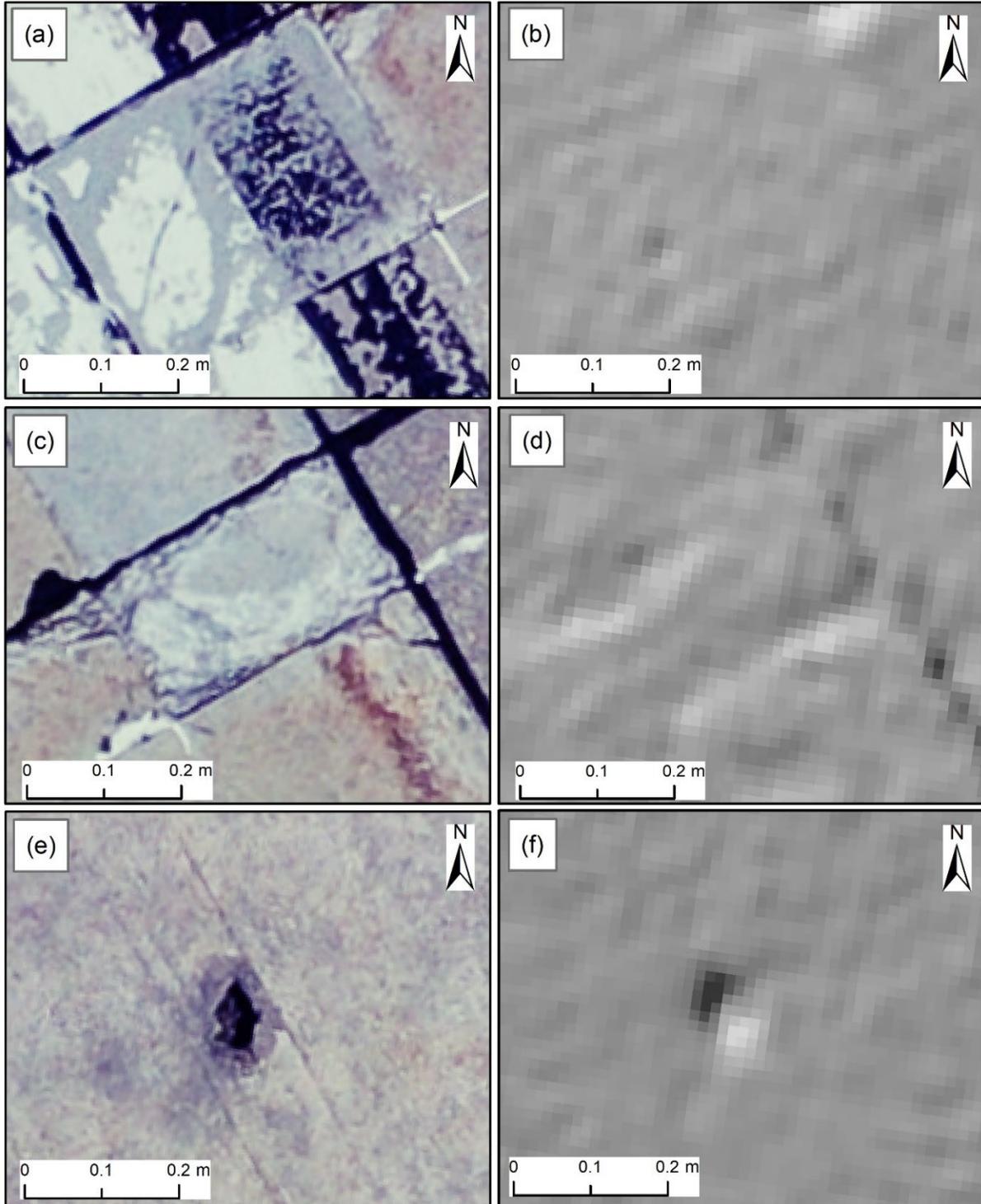


Figure 55. Low-severity Small Patching in (a) 3.2-mm/pix orthophoto and (b) 12.9-mm/pix DEM; Medium-severity Small Patching in (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and High-severity Small Patching in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

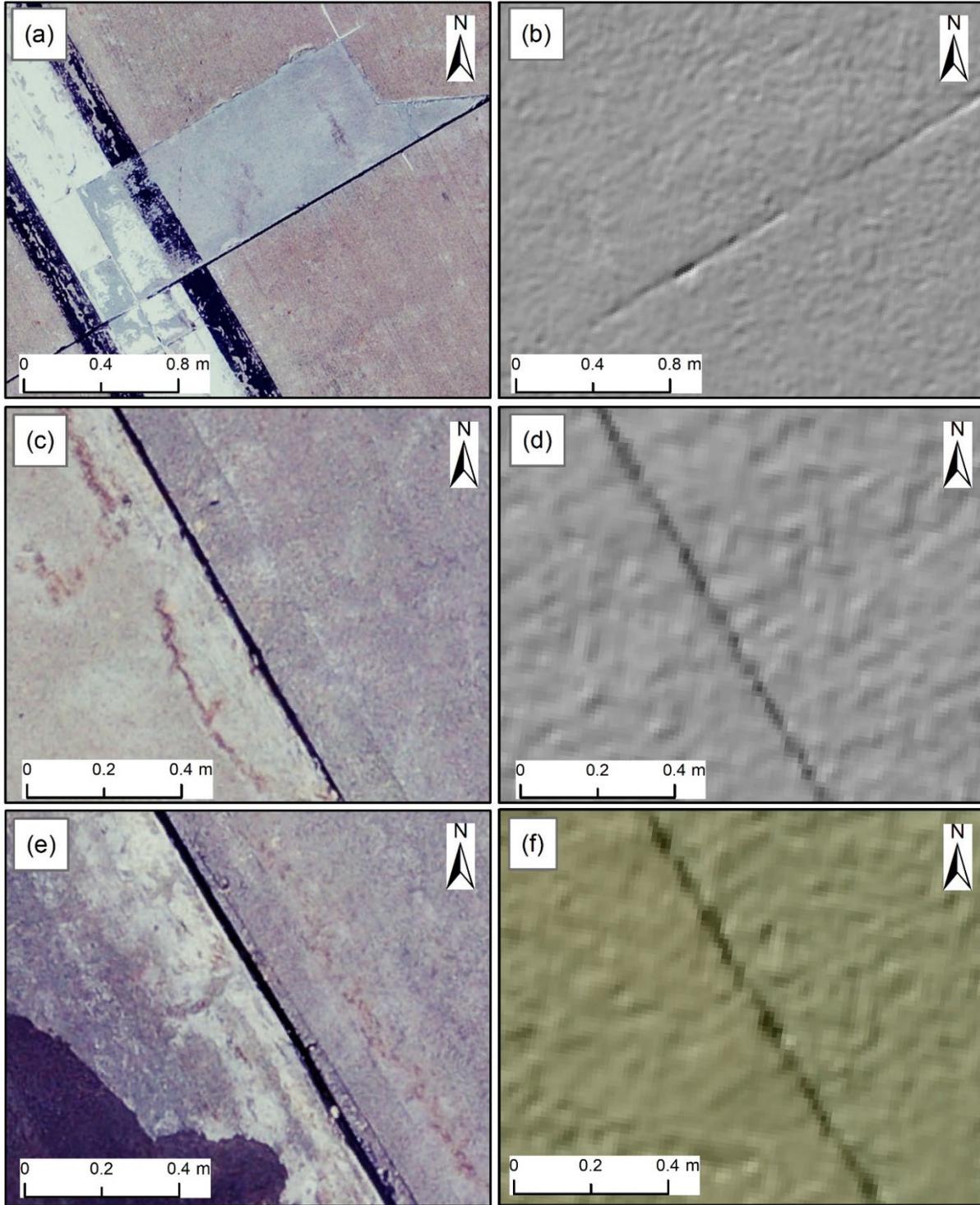


Figure 56. Low-severity Large Patching in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Medium-severity Faulting in (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and High-severity Faulting in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

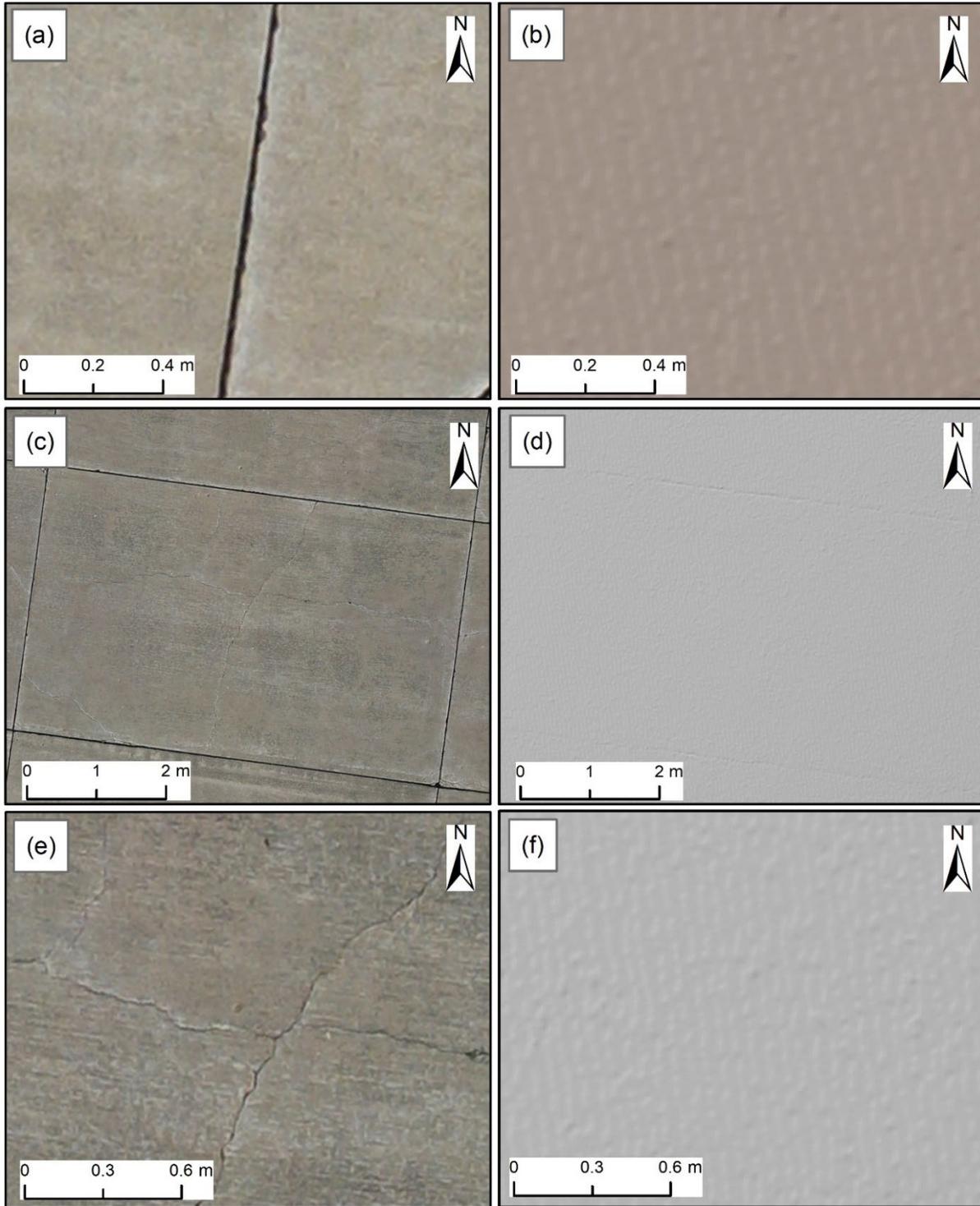


Figure 57. Low-severity Faulting in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM and Medium-severity Shattered Slabs in (c, e) 2.5-mm/pix Orthophoto and (d, f) 10-mm/pix DEM

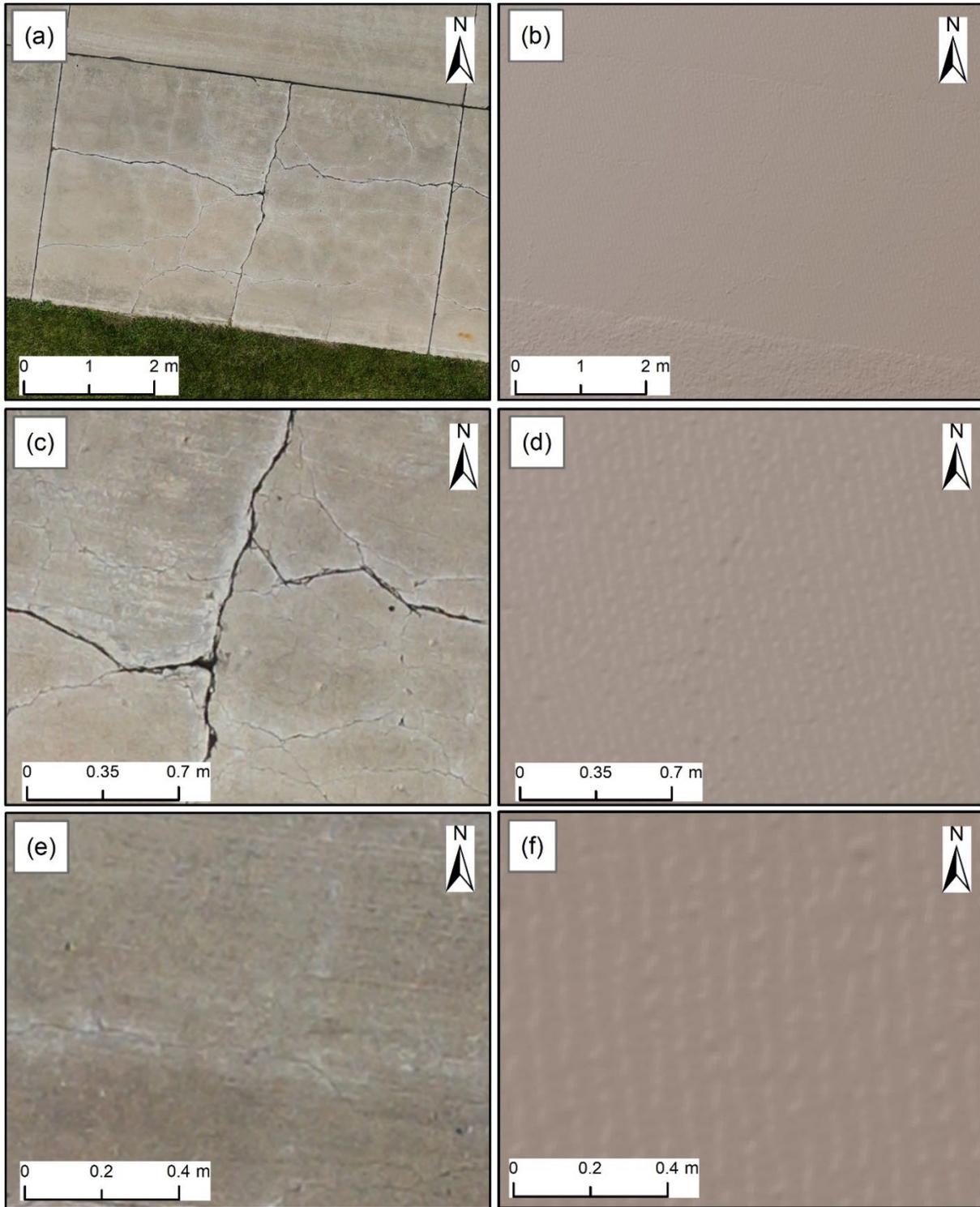


Figure 58. High-severity Shattered Slab in (a, c) 2.5-mm/pix Orthophoto and (b, d) 10-mm/pix DEM and Shrinkage Crack in (e) 2.5-mm/pix Orthophoto and (f) 10-mm/pix DEM

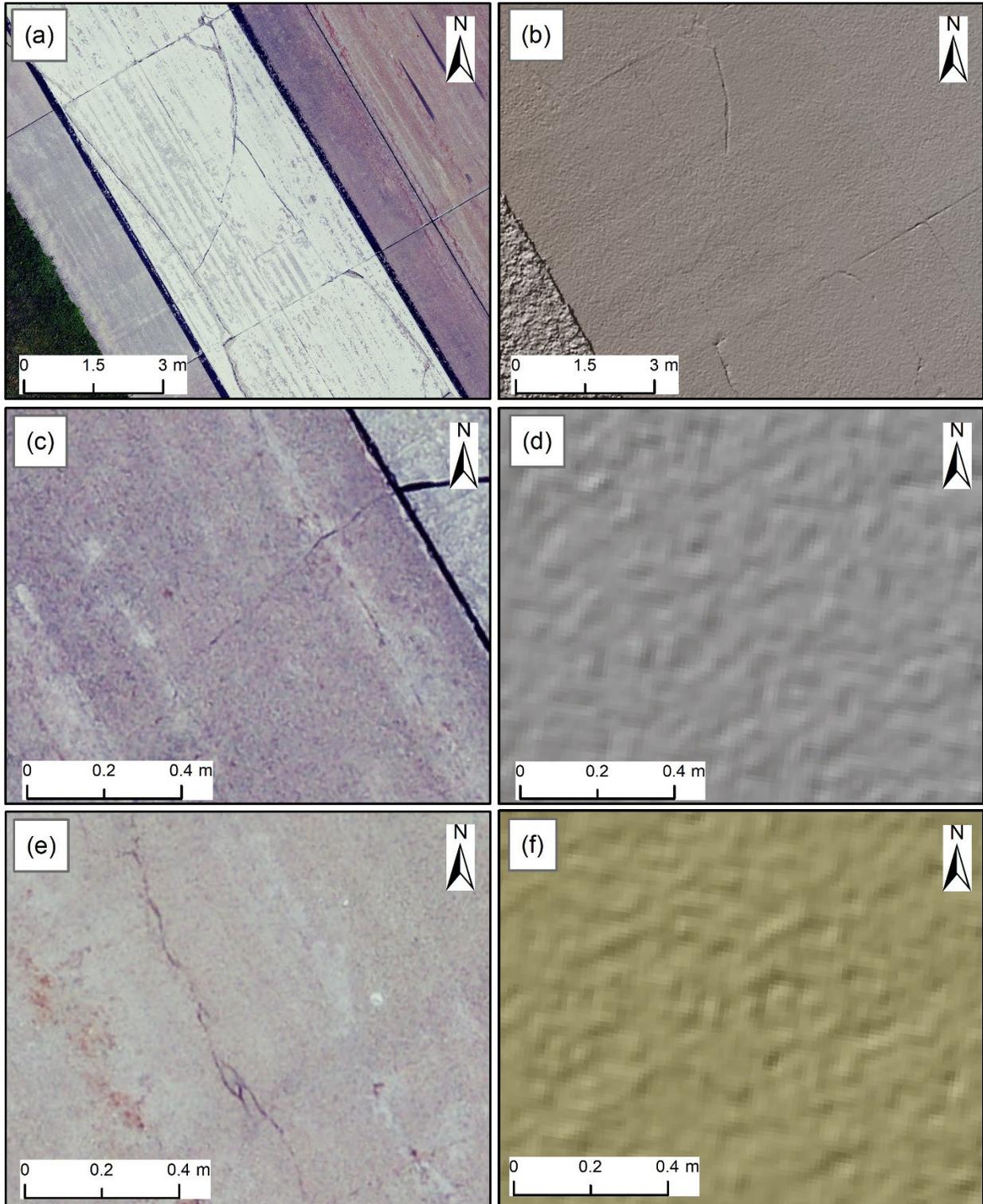


Figure 59. Medium-severity Shattered Slab in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Shrinkage Crack (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and Low-severity ASR in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

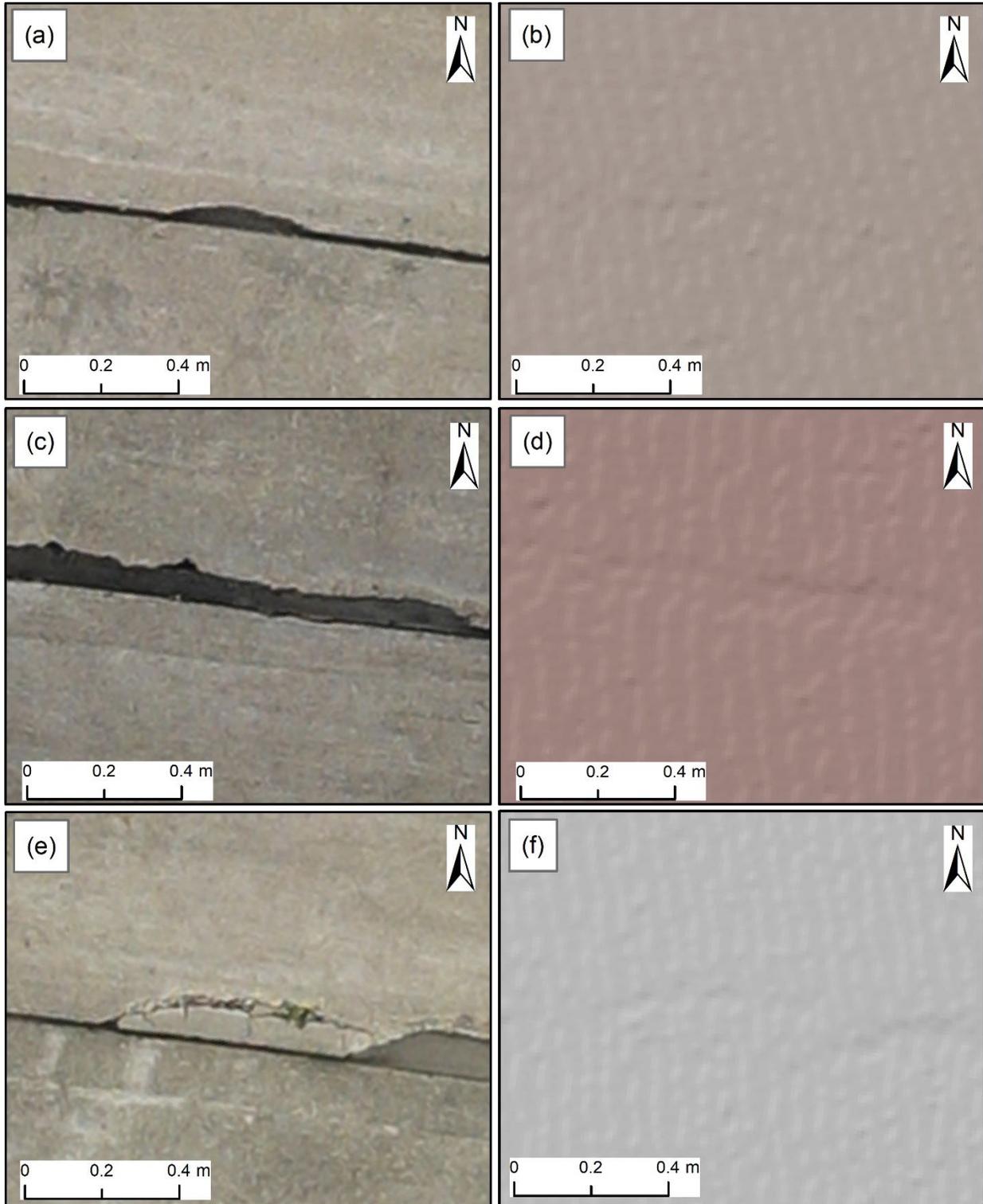


Figure 60. Low-severity Joint Spalling in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM; Medium-severity Joint Spalling in (c) 2.5-mm/pix Orthophoto and (d) 10-mm/pix DEM; and High-severity Joint Spalling in (e) 2.5-mm/pix Orthophoto and (f) 10-mm/pix DEM

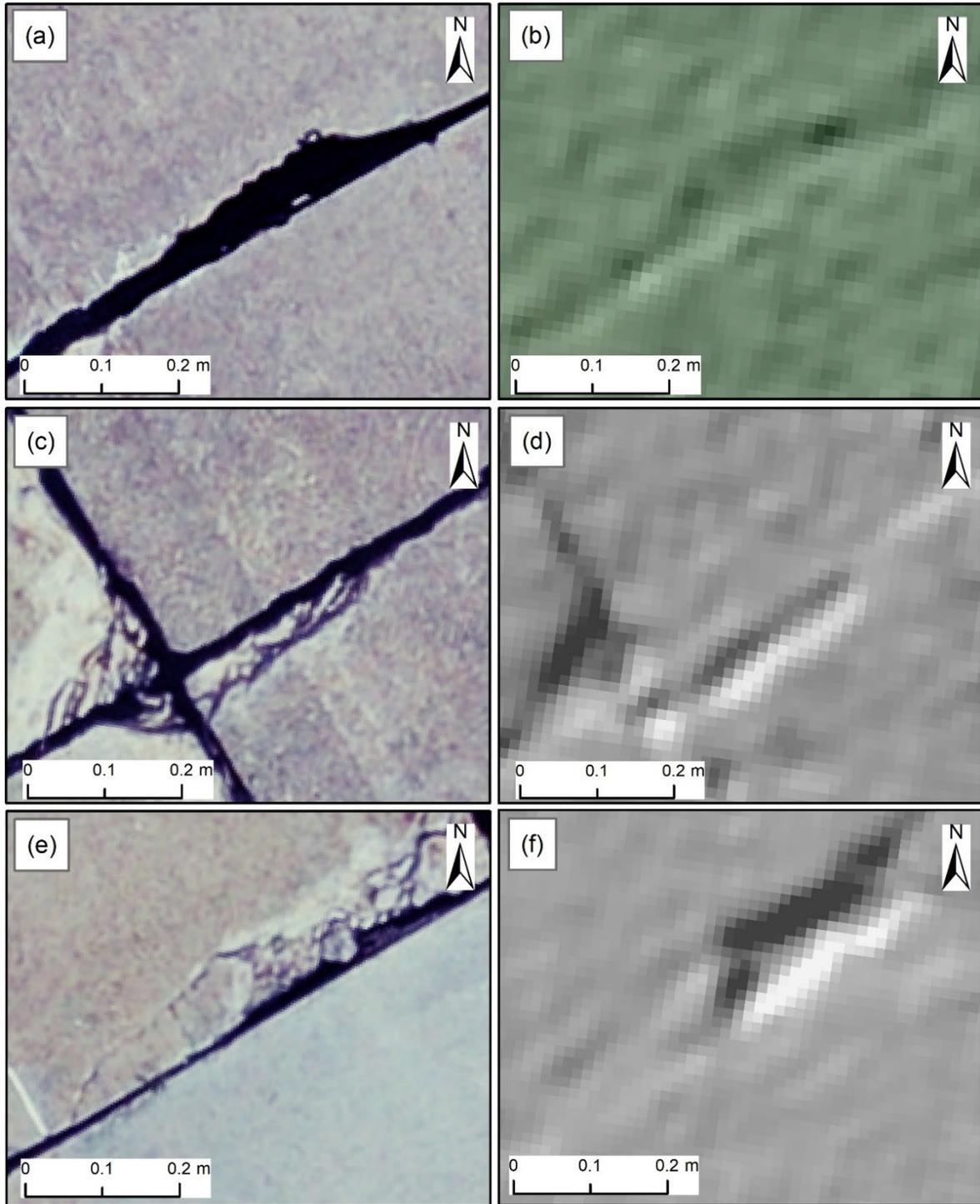


Figure 61. Low-severity Joint Spalling in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Medium-severity Joint Spalling on right and Medium-severity Corner Spalling on left in (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and High-severity Joint Spalling in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

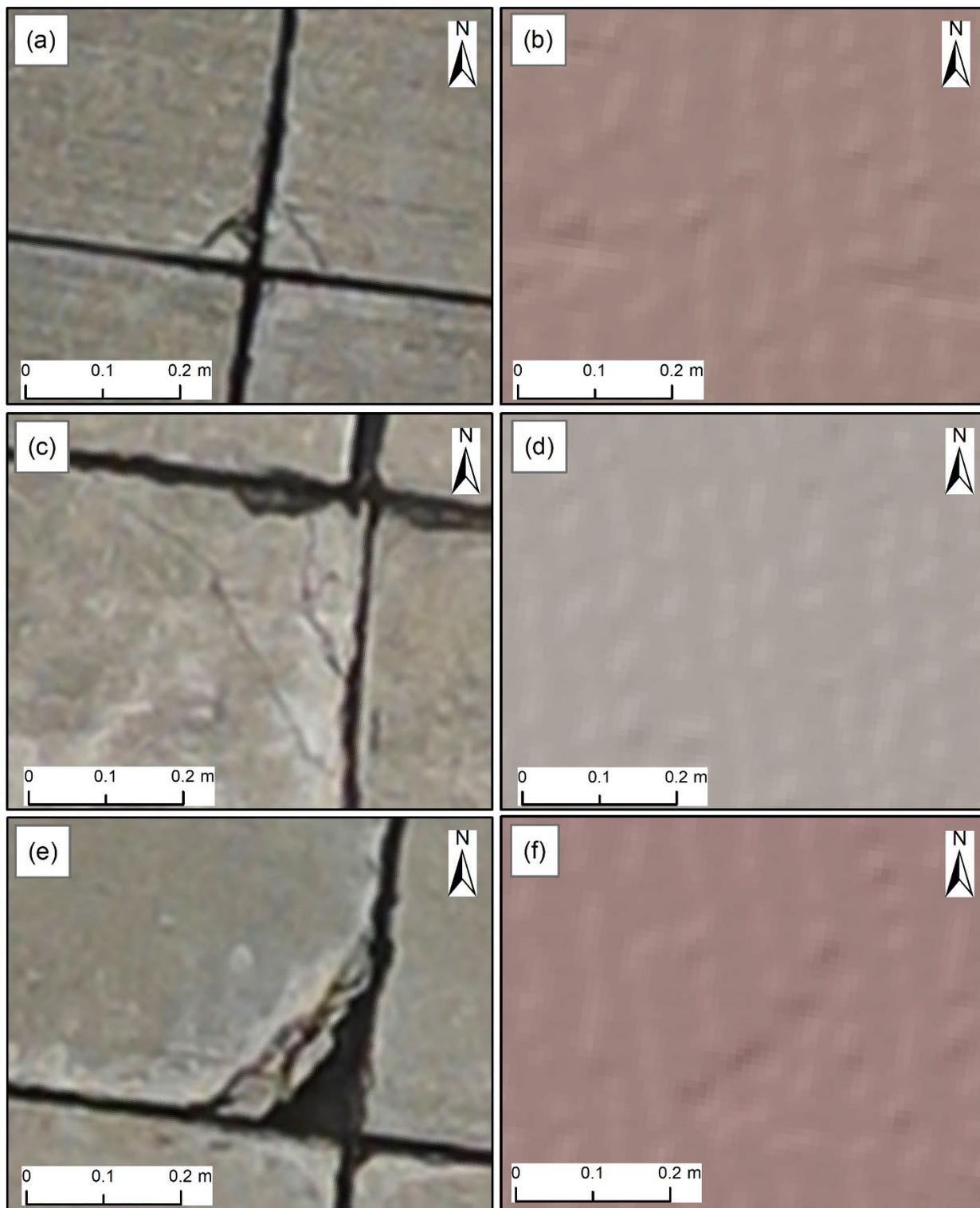


Figure 62. Low-severity Corner Spalling in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM; Medium-severity Corner Spalling in (c) 2.5-mm/pix Orthophoto and (d) 10-mm/pix DEM; and High-severity Corner Spalling in (e) 2.5-mm/pix Orthophoto and (f) 10-mm/pix DEM

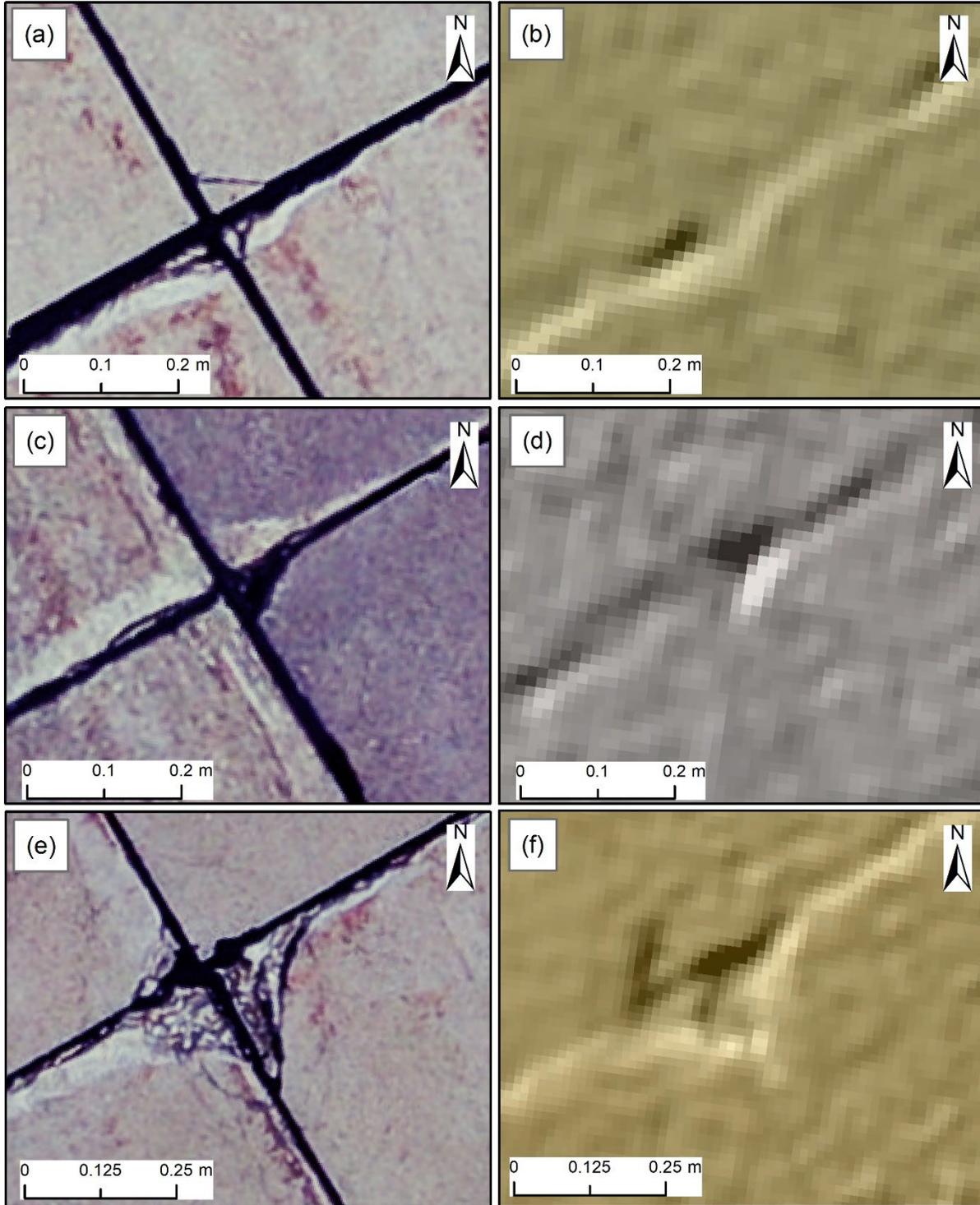


Figure 63. Low-severity Corner Spalling on top and Low-severity ASR on bottom left and bottom right of Joint Intersection in (a) 3.2-mm/pix Orthophoto and (b) 12.9-mm/pix DEM; Medium-severity Corner Spalling on left in (c) 3.2-mm/pix Orthophoto and (d) 12.9-mm/pix DEM; and High-severity ASR in (e) 3.2-mm/pix Orthophoto and (f) 12.9-mm/pix DEM

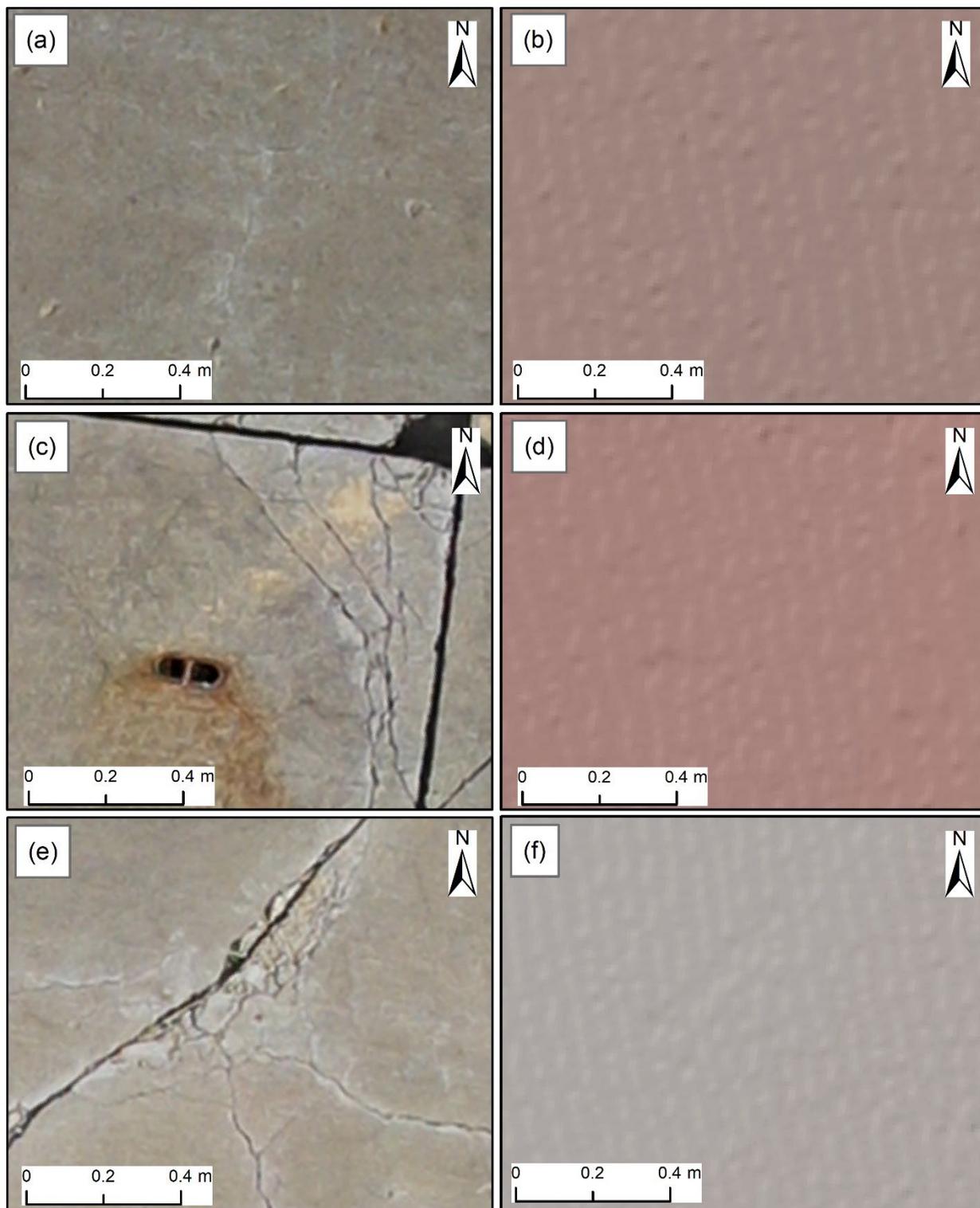


Figure 64. Low-severity ASR in (a) 2.5-mm/pix Orthophoto and (b) 10-mm/pix DEM; Medium-severity ASR in (c) 2.5-mm/pix Orthophoto and (d) 10-mm/pix DEM; and High-severity ASR in (e) 2.5-mm/pix Orthophoto and (f) 10-mm/pix DEM

The orthophoto of Runway 14/32 and Taxiway A of PRO was imported into ArcGIS Pro for visual identification of the pavement distresses. Each PCC pavement distress was identified with its associated severity levels and documented on a shapefile. PCI values for the sample units were calculated based on the documented distresses and their severity level by following the standard procedure outline on ASTM D5340-20. The sUAS-based PCI value and FOG PCI value for each sample are plotted and shown in Figure 65.

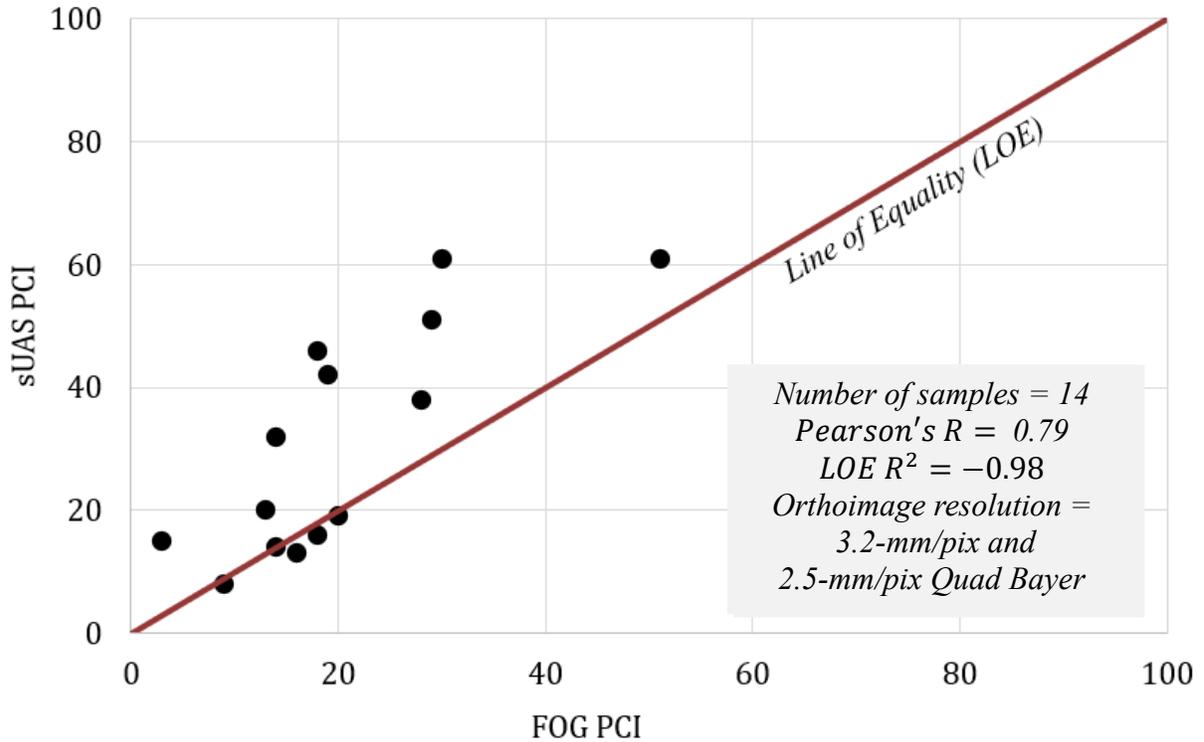


Figure 65. Foot-on-ground PCI vs sUAS PCI Calculated Using 2.5-mm/pix and 3.2-mm/pix Data of PRO

The sUAS PCI values were relatively higher than the FOG PCI value because faulting of different severity was challenging to identify in DEM with resolution of more than 10 mm/pix. DEM of 3 mm/pix was useful in confirming the suspected location faulting at ONZ. The PRO data also showed that the low-severity ASR was often not appropriately identified, like BNW and ONZ.

## 5. FIELD DEMONSTRATION IN NEW JERSEY

### 5.1 CAPE MAY AIRPORT IN AUGUST 2021

#### 5.1.1 Objectives

Cape May Airport (WWD) in southern New Jersey was selected by the FAA to demonstrate the capability of sUASs to identify and rate different airfield pavement distresses using lessons learned earlier in this project. The research team collected PCIs, sUASs, and data from WWD between August 23 and 26, 2021. The lessons learned from the airports in Michigan, Illinois, and Iowa

were used to select sUAS systems, sensors, and flight parameters for deployment at this airport. The objectives of this field demonstration are summarized as follows:

- Showcase the capabilities of the recommended sUAS platform and sensors for airfield pavement distress identification
- Collect sUAS data from identical sample units where previous PCI surveys were conducted and the third-party-collected sUAS data

### 5.1.2 Field Demonstration in August 2021

A complete field demonstration plan developed for WWD was executed from August 23 through 26, 2021. The data collection team collected sUAS and PCI survey data following all the standard safety protocols. The PCI data collection team arrived at Cape May, NJ, on August 22, 2021, and collected data from August 23 through 25, 2021. The sUAS data collection team arrived at Atlantic City, NJ, on August 23, 2021, and collected the sUAS data from August 24 through 26, 2021.

WWD is the airport selected by the FAA to demonstrate the capability of sUAS to identify and rate different airfield pavement distresses. At the request of the FAA, the research team focused on collecting complete sUAS data at 1.5 mm/pix from the Runway 10/28, Fixed Base Operator (FBO) Apron Section 30, and FBO Apron Section 40. The Nikon D850 45.7-mp camera with 50-mm prime lens was mounted on the newly available Tarot X6 (manufactured by UAV Systems International of Las Vegas, NV, with the U.S.-made Pixhawk flight controller) and flown at 18.3 m to collect the 1.5-mm/pix resolution data. In addition, backup data were collected using Mavic 2 Pro with 20-mp optical RGB camera at 15.2 m altitude and M2EA with 48-mp Quad Bayer RGB camera at 24.4 m, which resulted in an orthophoto resolution of 3.5 mm/pix and 4.1 mm/pix, respectively. The M2EA UAV also collected thermal data to potentially help with distress detection using its onboard 640x512 radiometric 30-hz thermal camera. In addition to the complete data collection, the highest resolution (<1 mm/pix) sample units' data were also collected for nine focus sample units, as shown in . The mdMapper-1000+ with its Sony RX1R-II 42.4 mp was flown to collect data from 18.3 m and 9.1 m in height to demonstrate its potential when sufficiently low wind conditions are present, but an unexpected software bug in the flight-control application prevented successful data collection over most areas. For the limited areas collected, the 18.3 m height data mdMapper/Sony collections yielded orthophotos with 2.2 mm/pix resolution and DEMs with 8.9 mm/pix resolution. The 9.1 m height mdMapper/Sony data collections yield orthophotos with 1.2 mm/pix resolution and DEMs with 4.8 mm/pix.

As shown in Table 13, the sUAS data collection spanned three days. Collecting high-resolution 45.7-mp data with the Nikon D850 at a relatively low altitude (18.3 m) meant it took significant time to collect data with the Tarot X6 platform. In addition, there was longer downtime for battery charging and swapping because practical flight times with the batteries available at this time were limited to approximately eight to nine minutes. Therefore, the highest priority was given to this sUAS system. Longer-duration sUAS would shorten the amount of time required to collect 45.7-mp data at 18.3m altitude. GCPs were planned to be placed as shown in Figure 66 to facilitate reusing the AeroPoints for multiple data collections and efficiently collect data. There were 76 GCPs placed around the WWD data collection areas over three days of data collection.

Table 13. Summary of sUAS Data Collection at WWD

Date	Target area	sUAS platform	Sensors	AGL (m)	Resolution (mm/pix)	
					Orthophoto	DEM
August 24-26	Runway 10/28 and FBO Aprons	Tarot X6	45.7-mp optical RGB Nikon D850	18.3	1.5	5.9
		Mavic 2 Pro	20-mp optical RGB	15.2	3.5	14
		M2EA	512x640 thermal	24.4	31.5	NA
August 26	SUs (nine focus sample units)	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	*18.3	2.2	8.5
				*9.1	1.3	5.4
		Tarot X6	45.7-mp optical RGB Nikon D850	9.1	0.8	3

\*Collected over limited areas due to unexpected bug in mdMapper flight control software.

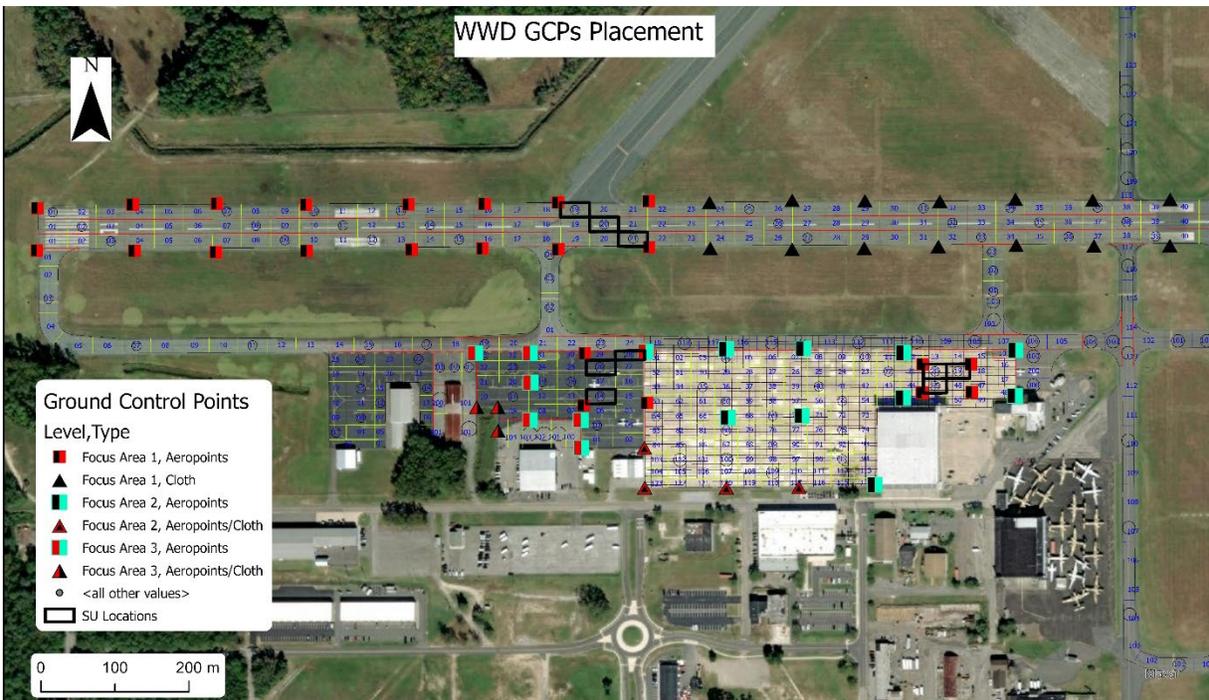


Figure 66. Overview of WWD and Sampling Focus Areas, Including Recommended Locations for 60 Planned GCPs

The data collection team followed the standard sUAS and Airport safety guidelines as outlined in Appendices O and P. Support was provided by two FAA employees to assist with the data collection. An FAA vehicle was used to recharge the sUAS batteries and take shade during the high-temperature, humid day. The inverter on the vehicle facilitated fast-charging multiple Tarot

X6 batteries at a time that would have taken a longer period in the typical charging station of the research team.

APTech conducted an airfield pavement distresses FOG survey using the ASTM D5340-20 standard at WWD. A two-person ground crew recorded the airfield distresses with a GPS-enabled tablet system between August 23 and 25, 2021. The PCI data collection team collected PCI data from 55 selected sample units of the different parts of Runway 10/28, FBO Apron Section 30, and FBO Apron Section 40. The sample units were selected based on the suggestions of the FAA TPOCs and previous PCI inspection reports.

### 5.1.3 Results and Discussions

All sUAS optical RGB data collected with different sensors were imported to Agisoft Metashape for processing. The locations of the images were corrected with GCP location information. Agisoft Metashape exported RGB orthophoto and DEM of high resolution as output, as mentioned in . The processing time for the primary sUAS sensor data, Nikon D850 45.7 mp, took a considerable amount of time because of the data volume. The DEMs were also used to generate hillshade for better visualization. DEM and orthophotos of different resolutions were compared to evaluate their capabilities in individual airfield pavement distress detection, as shown in Figure 67 through Figure 90. A summary of the following comparisons is also provided in Table 14. The data comparison showed:

- RGB orthophoto of 4.0-mm/pix resolution was adequate to detect most of the crack-based distresses and patching with different severity. However, they were not very useful in spalling detection and rating.
- 3.5-mm/pix orthophoto detected all the distresses detected by 4-mm/pix data. Additionally, spalling and ASR with different severity in PCC pavement and alligator cracking in AC pavement were also identified. However, misidentification between spalling and ASR in PCC pavement was also observed. In some cases, spalling and ASR detection were also found to be challenging.
- 1.5 mm/pix performed the best in the detection of different PCC and AC pavement distresses. Shrinkage crack of PCC pavement was identified only in this resolution.
- 2.7-, 5.9-, and 5-mm/pix DEMs were useful in some distress detection.
- The presence of the shoving and faulting was successfully confirmed by plotting elevation change perpendicular to the shoving and faulting using the 3D stack tool of ArcGIS Pro, as shown in Figure 67 and Figure 68.

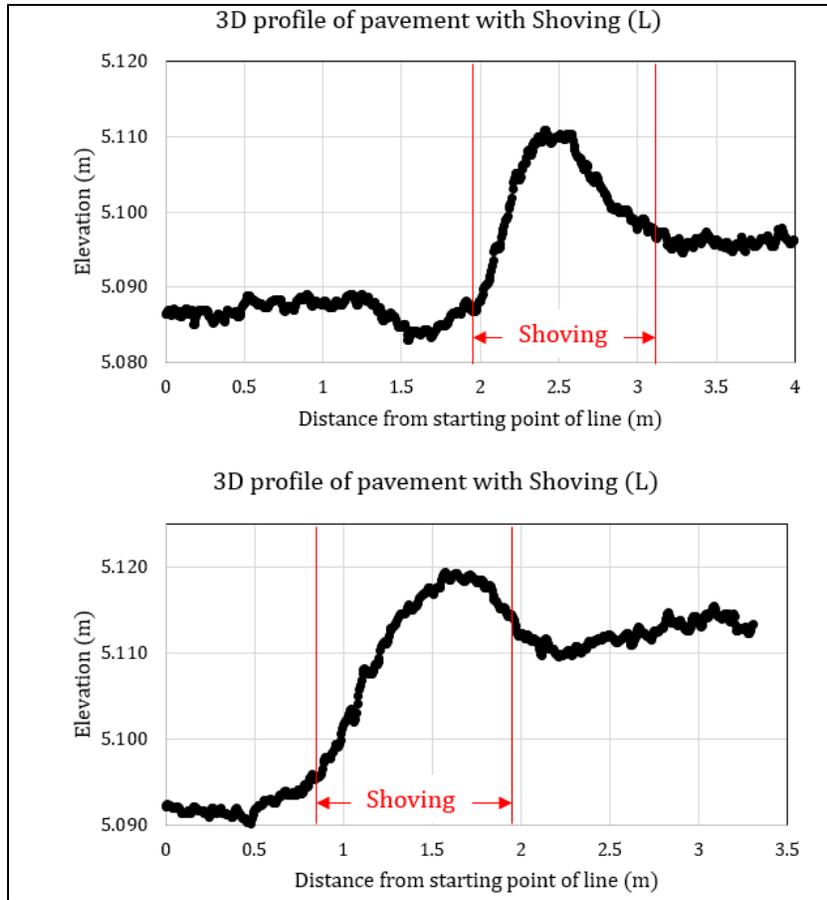


Figure 67. Low-severity Shoving Detection with 5.9-mm/pix Data

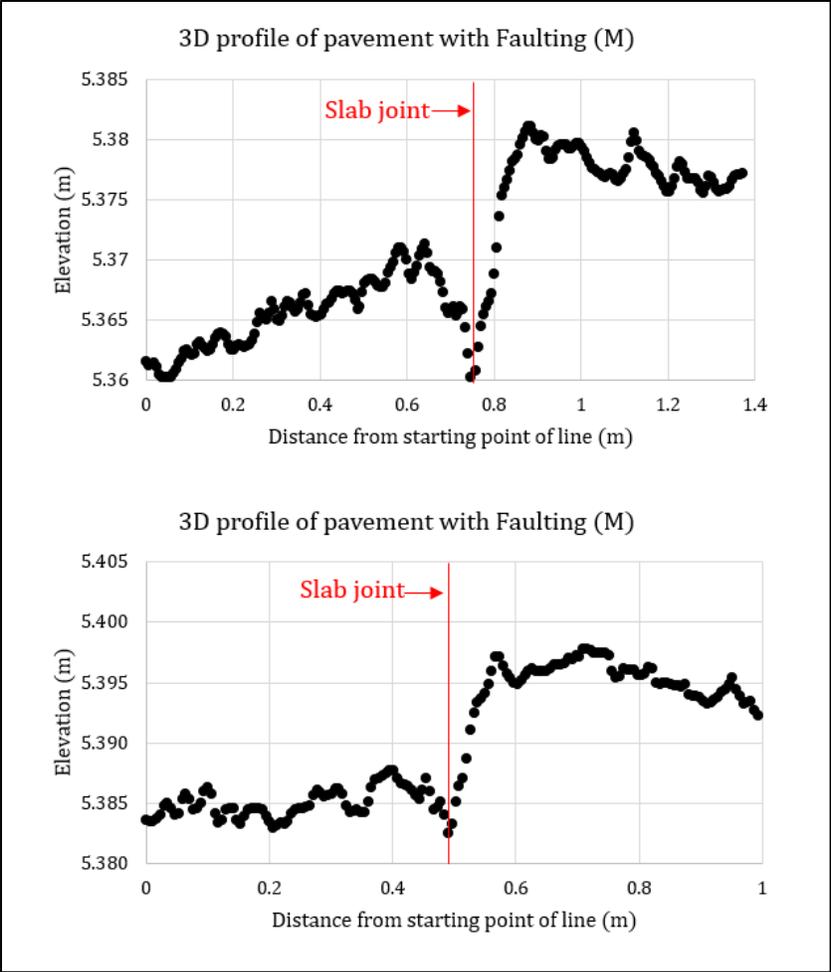


Figure 68. Medium-severity Faulting Detection in 5.9-mm/pix Data

Table 14. Summary of the Findings of WWD

ASTM D5340 Distress	Severity	Resolution Tested (mm/pix)		Highest Resolution (mm/pix)		Remarks
		RGB	DEM	RGB	DEM	
Alligator cracking (41)	L	1.5, 3.5, 4.1	5.9, 14, 16.2	3.5	5.9	Figure 69
Depression (45)	H	1.5, 2.2, 3.5, 4.1	5.9, 8.9, 14, 16.2	4.1	16.2	Figure 70
L&T cracking (48)	L, M	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	4.1	5.9	Figure 71 Figure 72
	H	1.5, 3.5, 4.1	5.9, 14, 16.2	4.1	16.2	Figure 73
Patching (50)	L, H, M	1.5, 2.2, 3.5, 4.1	5.9, 8.9 14, 16.2	4.1	16.2	
Raveling (52)	L, M, H	1.5, 2.2, 3.5, 4.1	5.9, 8.9 14, 16.2	1.5	ND	
Shoving (54)	L	1.5, 3.5, 4.1	5.9, 14, 16.2	ND	5.9	
Weathering (57)	L, M, H	1.5, 2.2, 3.5, 4.1	5.9, 8.9 14, 16.2	ND	ND	Figure 74
LTD cracks (63)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	4.1	5.9	Figure 75
	M			4.1	5.9	Figure 76
	H	1.5, 3.5, 4.1	5.9, 14, 16.2	4.1	5.9	Figure 77
Joint seal damage (65)	L	1.5, 3.5, 4.1	5.9, 14, 16.2	ND	ND	
Small patching (66)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	4.1	2.7	Figure 78
	M			4.1	2.7	Figure 78
	H	1.5, 3.5, 4.1	5.9, 14, 16.2	4.1	5.9	Figure 79
Large patching (67)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	4.1	5.9	Figure 80
	M	1.5, 3.5, 4.1	5.9, 14, 16.2	4.1	5.9	Figure 81
Faulting (71)	L	1.5, 3.5, 4.1	5.9, 14, 16.2	ND	ND	
	M	1.5, 3.5, 4.1	5.9, 14, 16.2	ND	5.9	
Shrinkage crack (73)	N/A	1.5, 3.5, 4.1	5.9, 14, 16.2	1.5	ND	Figure 82
Joint spalling (74)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	3.5	5.9	Figure 83
	M	1.5, 3.5, 4.1	5.9, 14, 16.2	3.5	14	Figure 84
Corner spalling (75)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	3.5	5.9	Figure 85
	M			3.5	5.9	Figure 86
	H			4.1	5.9	Figure 87
ASR (76)	L	0.7, 1.5, 3.5, 4.1	2.7, 5.9, 14, 16.2	3.5	5.9	Figure 88 Figure 78
	M			3.5	5.9	Figure 89
	H	1.5, 3.5, 4.1	5.9, 14, 16.2	3.5	5.9	Figure 90

All 4.1 mm/pix is not true resolution due to being derived from the Mavic 2 Enterprise Advanced 48-mp Quad Bayer camera.

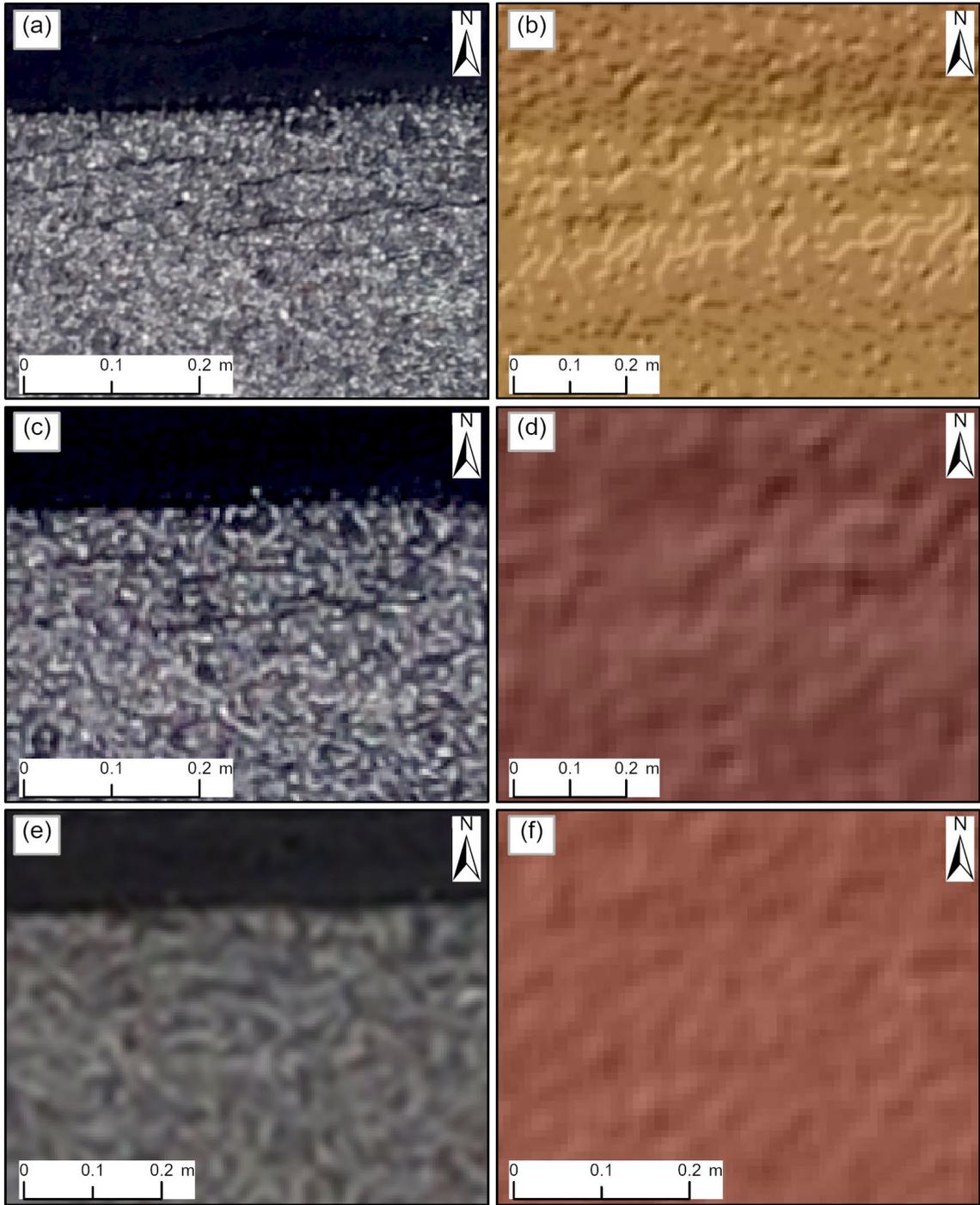


Figure 69. Low-severity Alligator Cracking (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

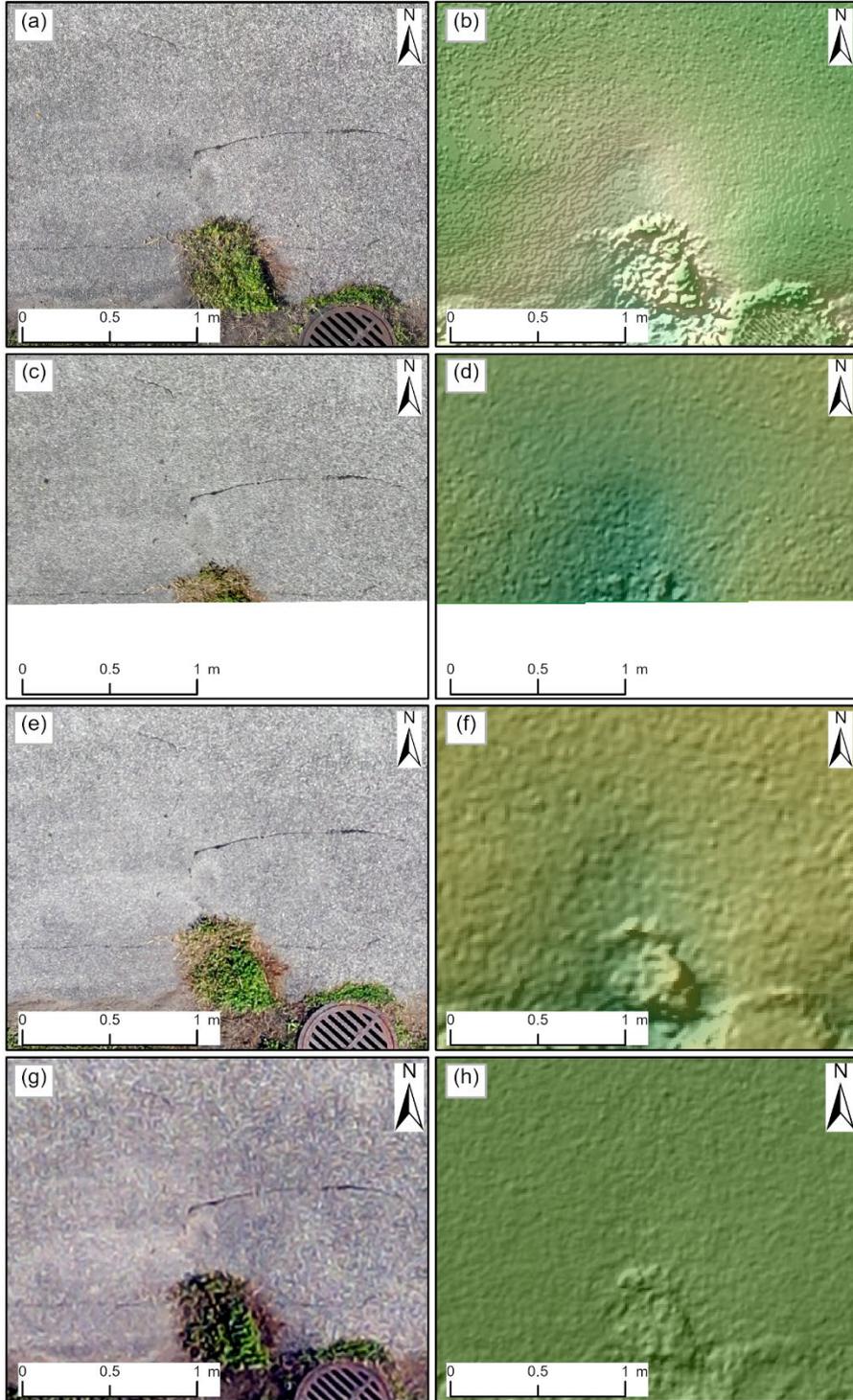


Figure 70. Depression in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 2.2-mm/pix Orthophoto, (d) 8.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

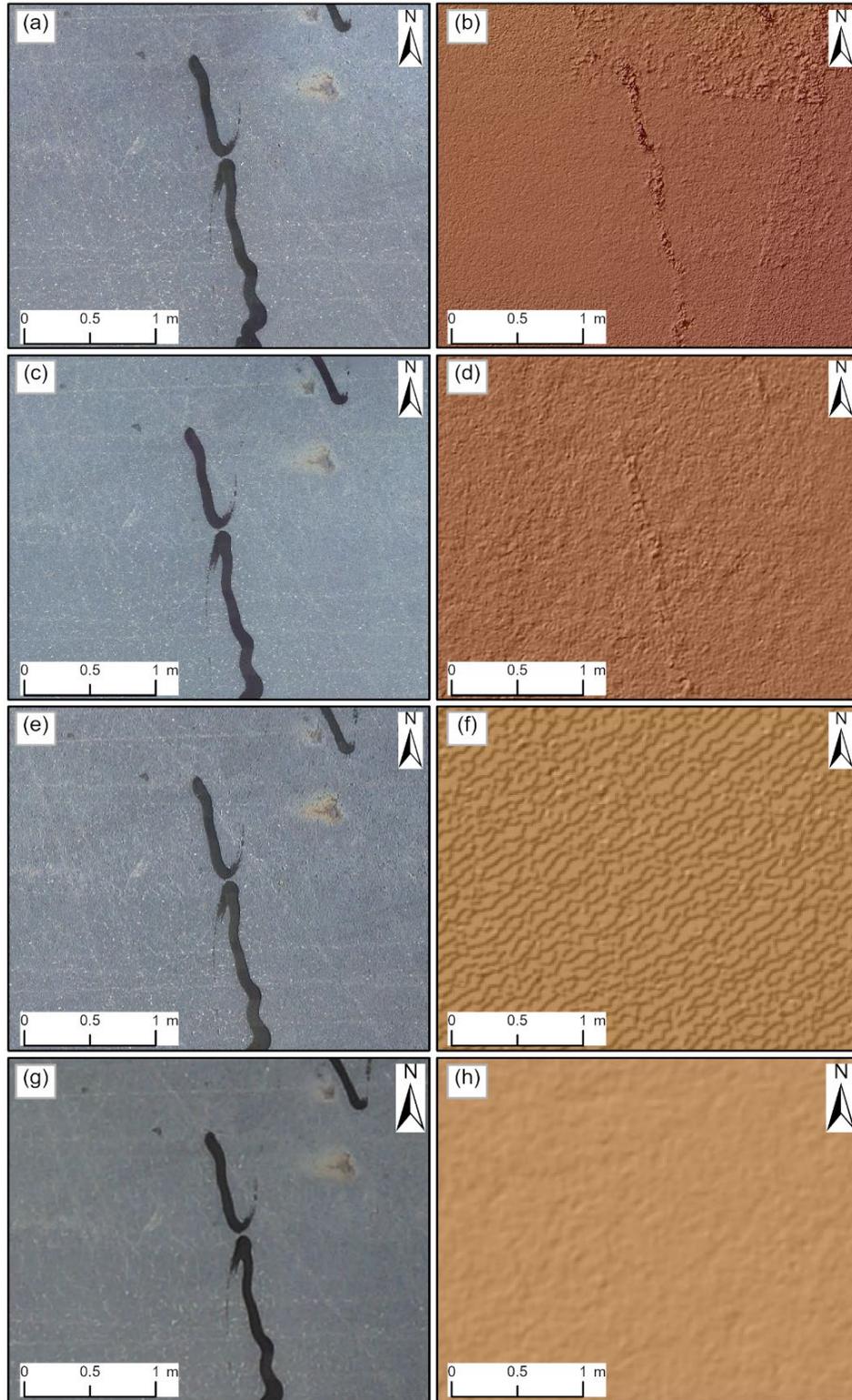


Figure 71. Low-severity L&T Cracks in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

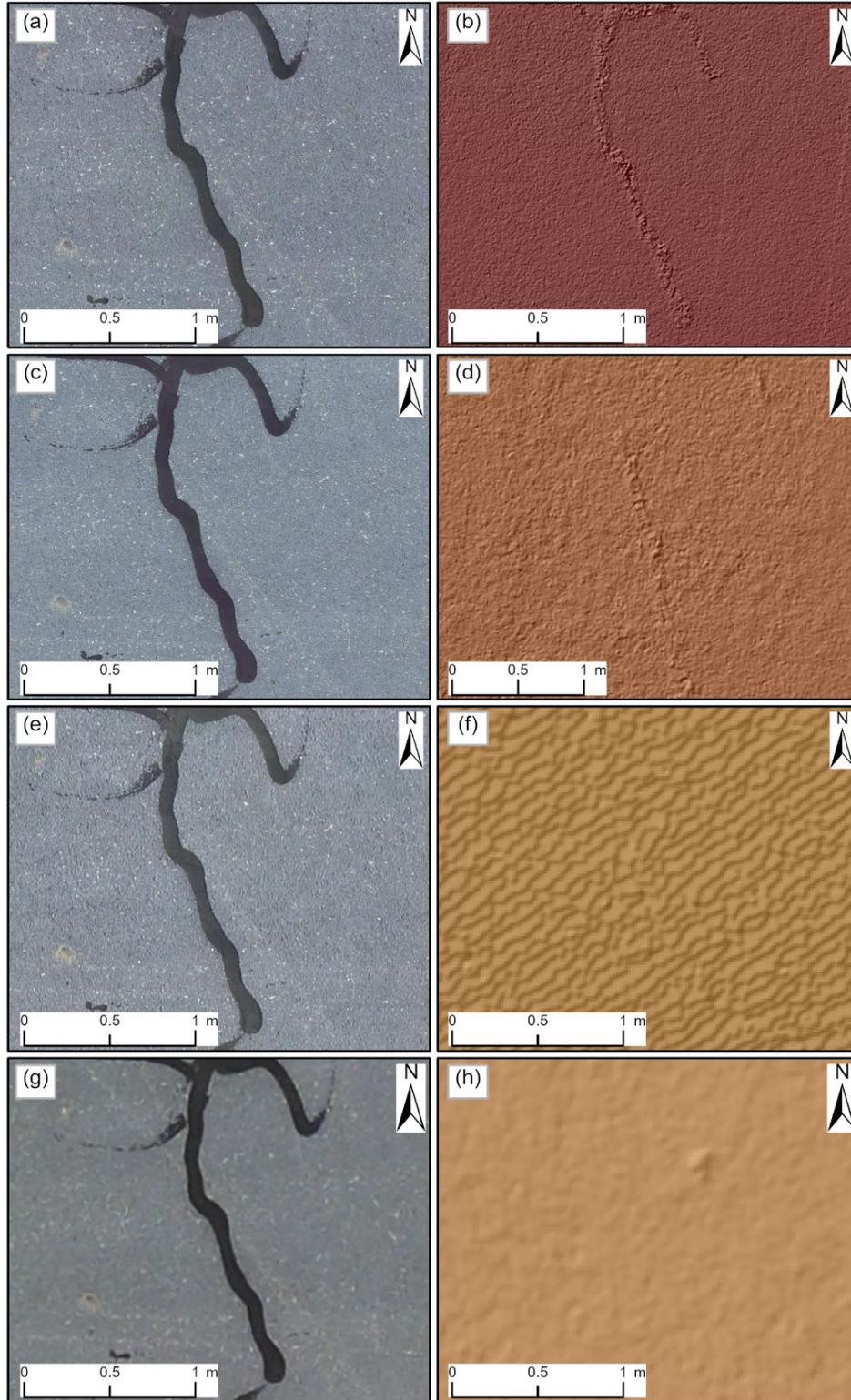


Figure 72. Medium-severity L&T Cracks in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

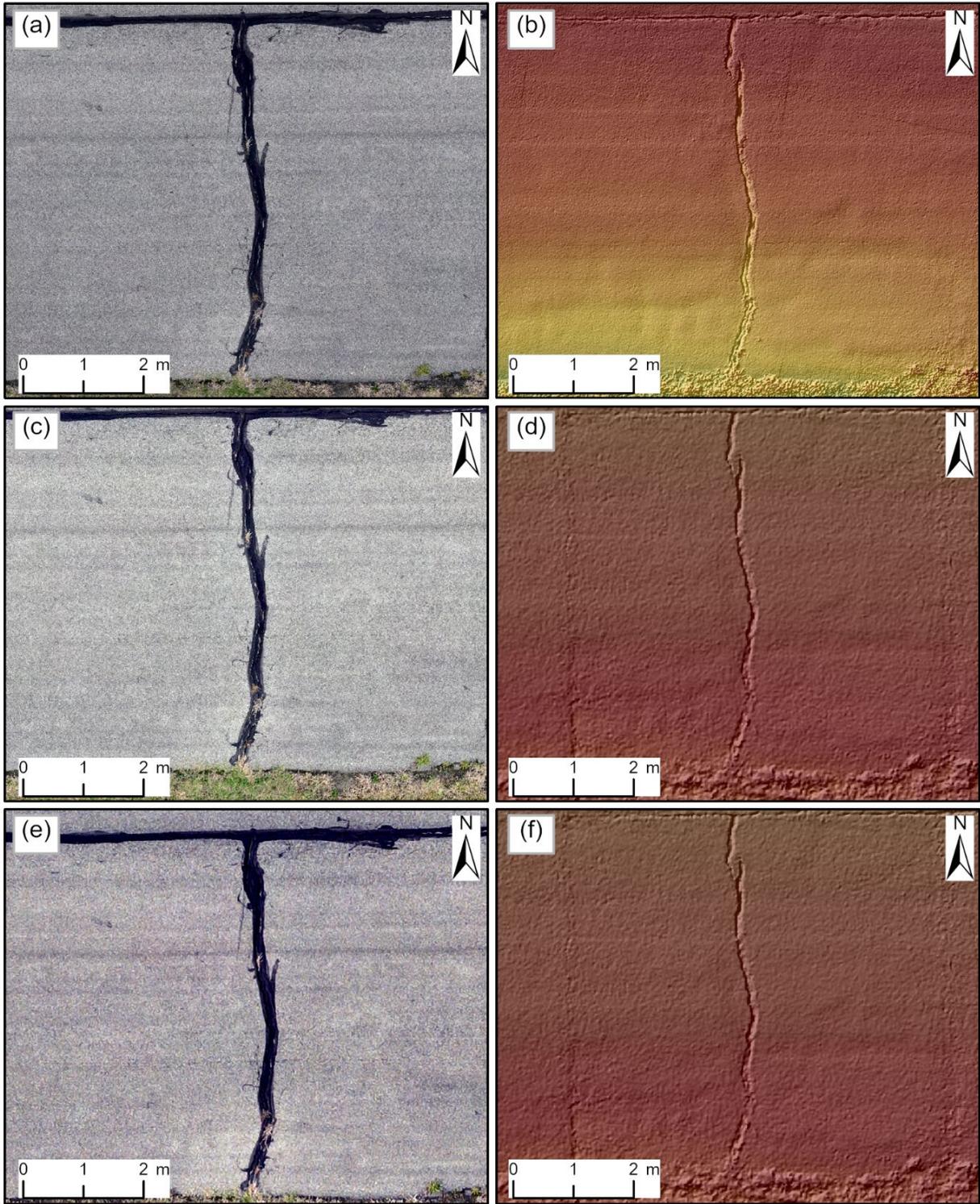


Figure 73. High-severity LTD Cracks in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

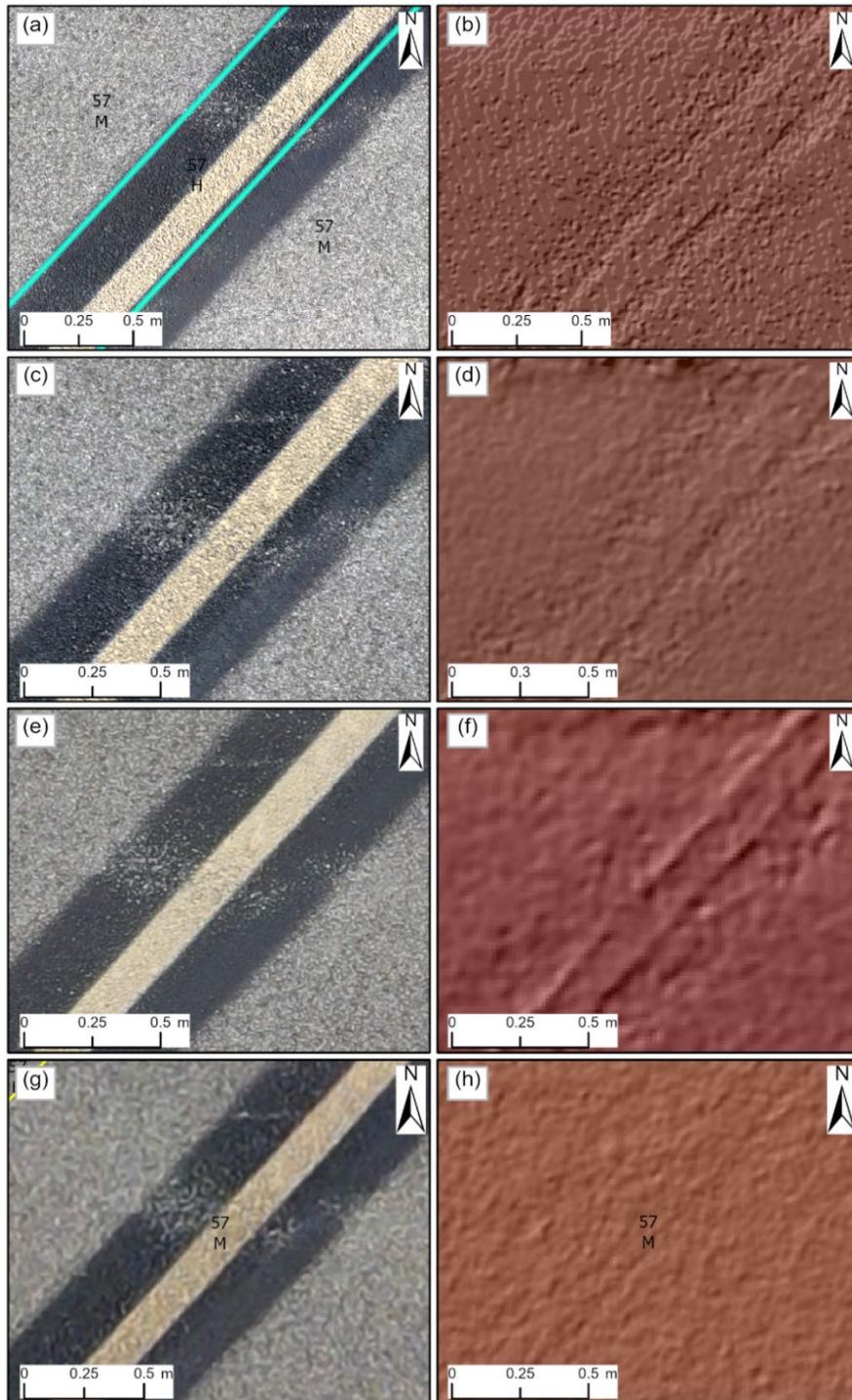


Figure 74. High-severity Weathering in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 2.2-mm/pix Orthophoto, (d) 8.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

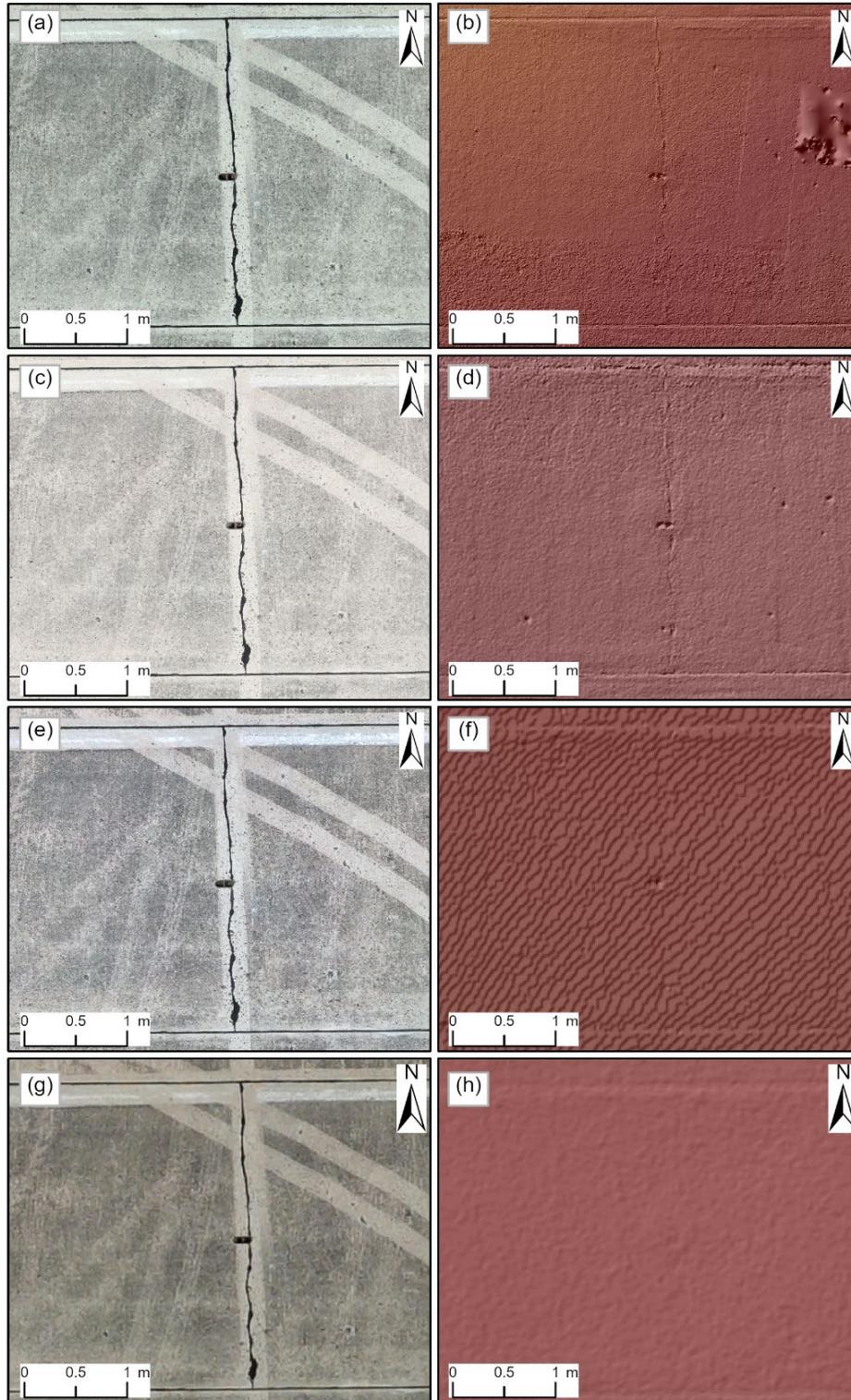


Figure 75. Low-severity LTD Cracks in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

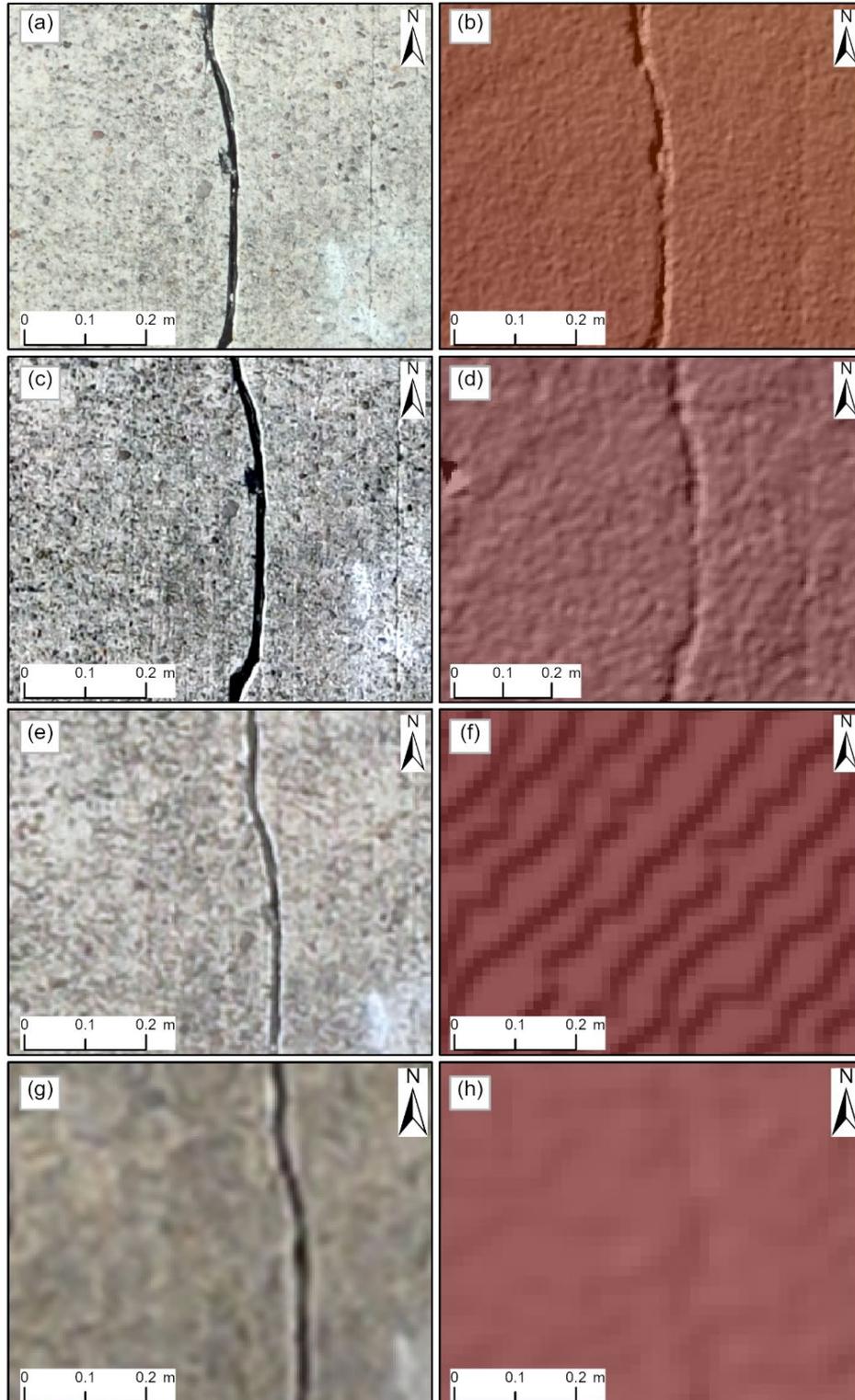


Figure 76. Medium-severity LTD Cracks in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

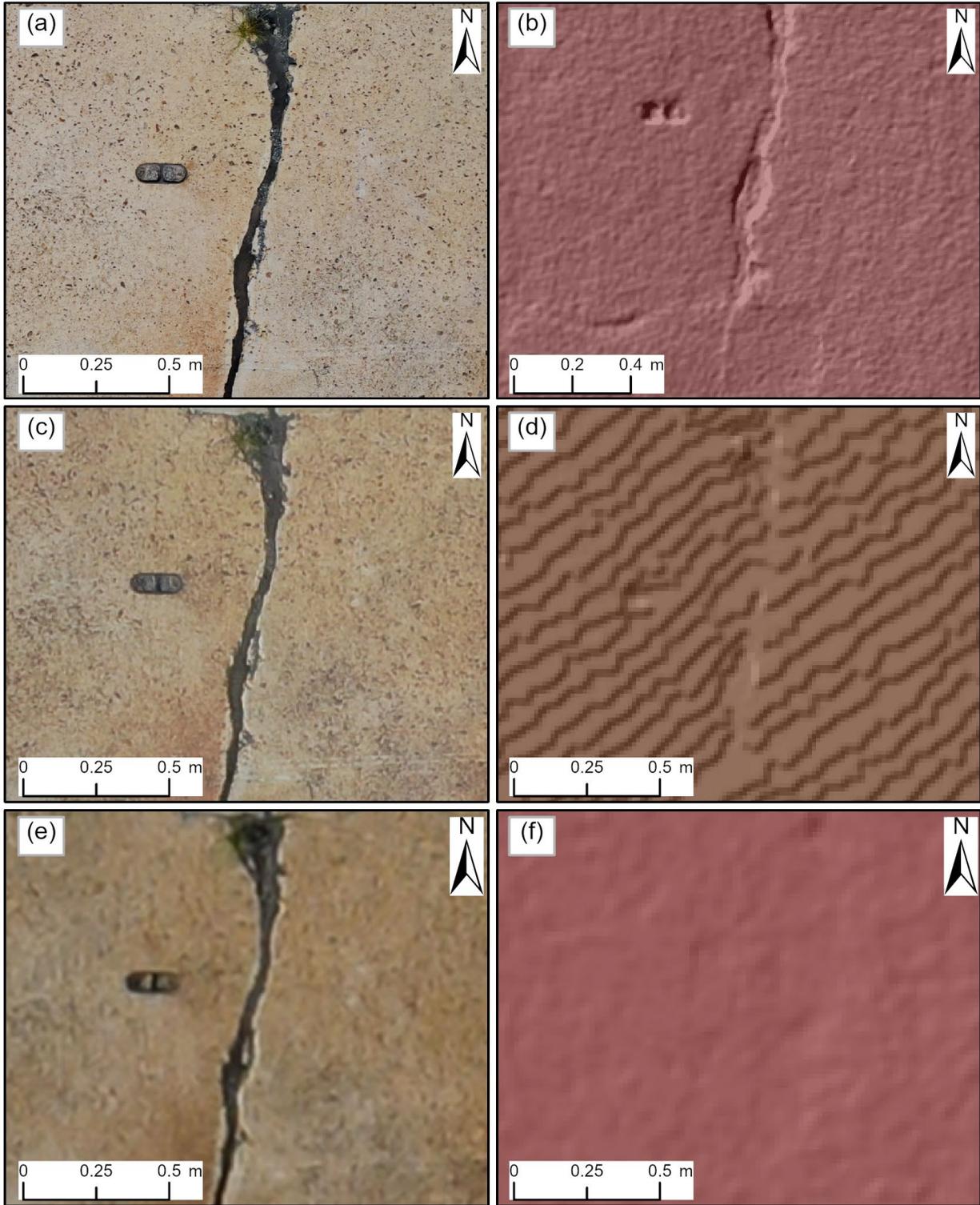


Figure 77. High-severity LTD Cracks in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

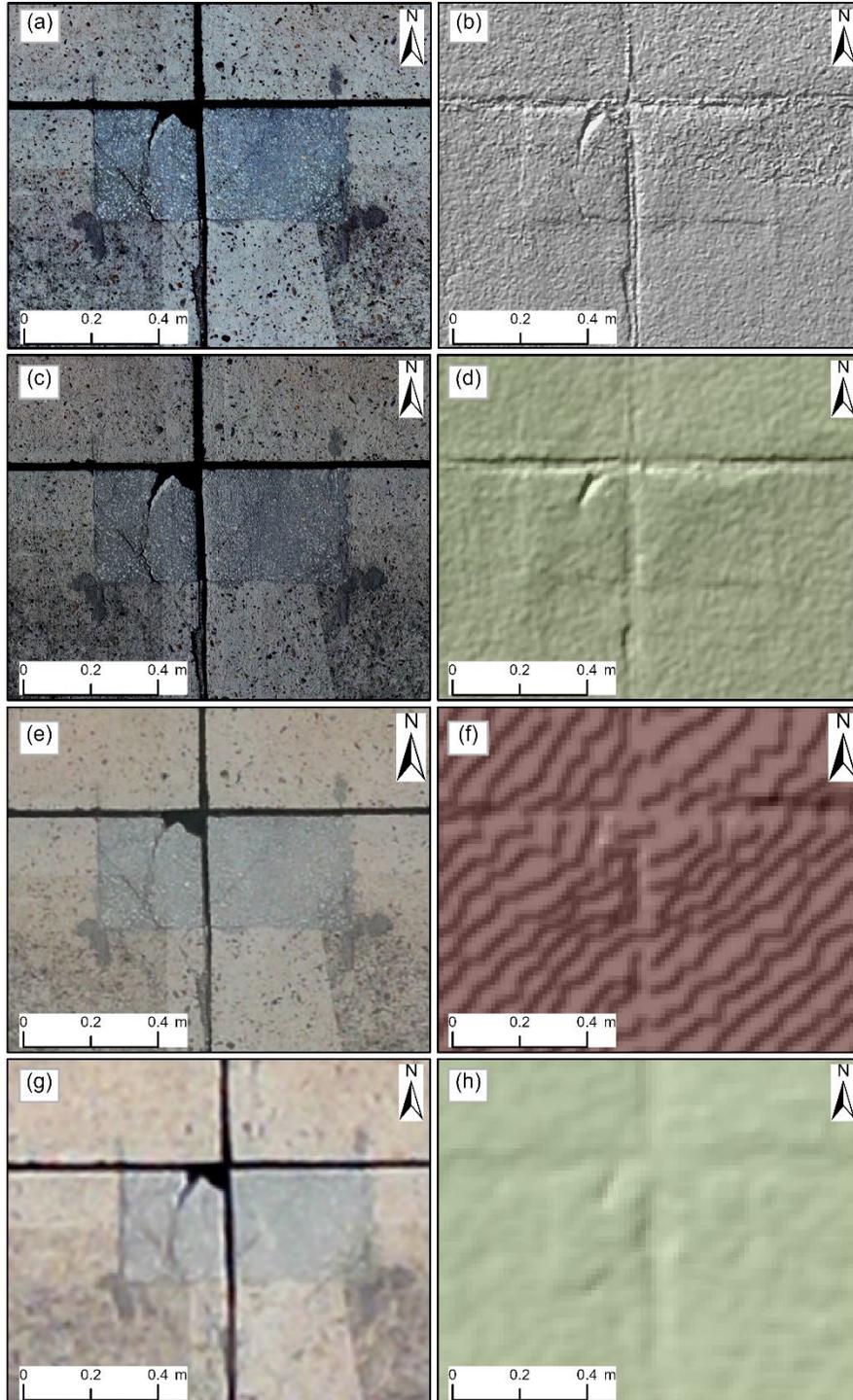


Figure 78. Low-severity Small Patching (L) on Right Quadrant, Medium-severity Small Patching on Left Quadrant, and Low-severity ASR in bottom of the Low-severity Small Patching in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

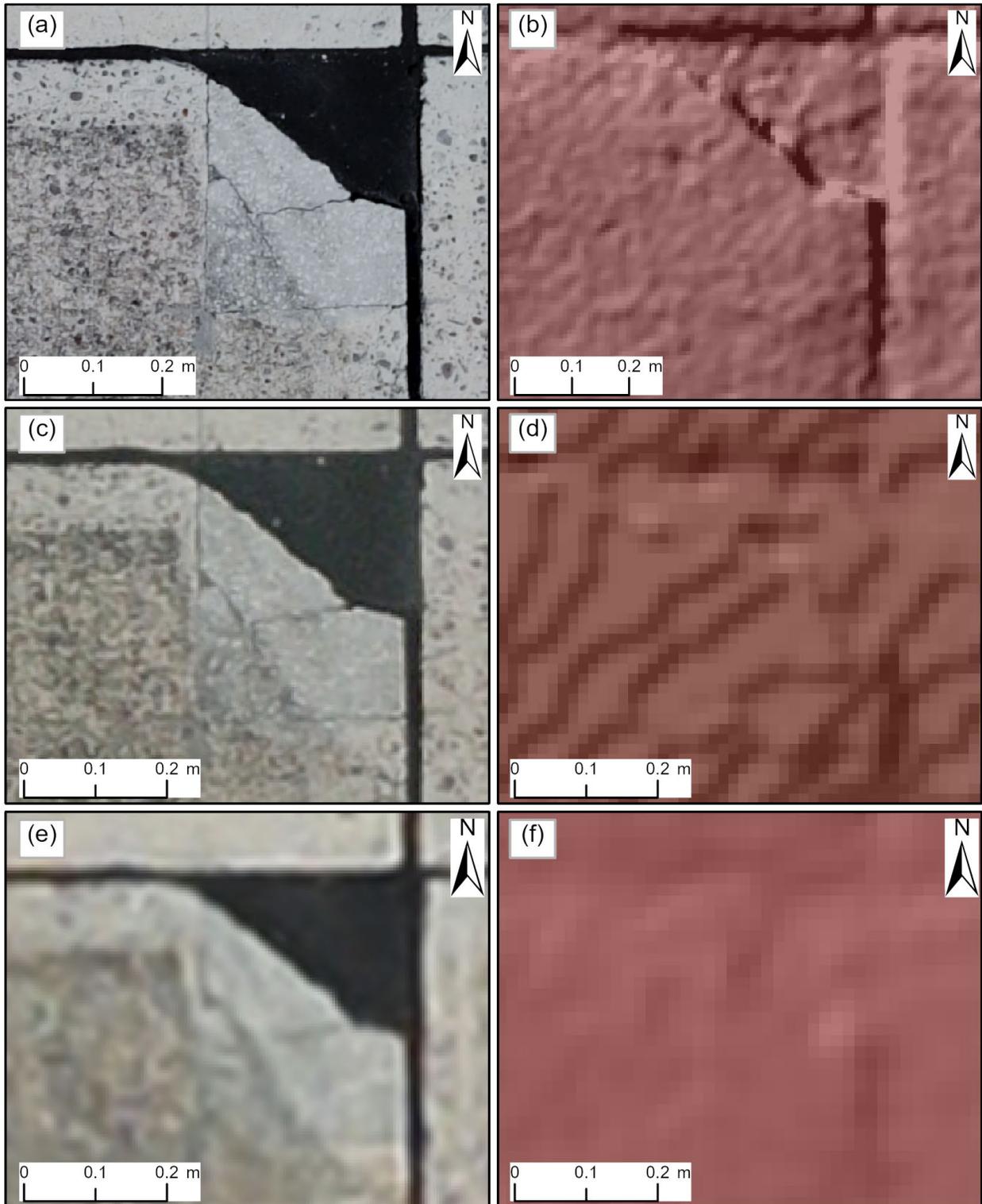


Figure 79. High-severity Small Patching in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

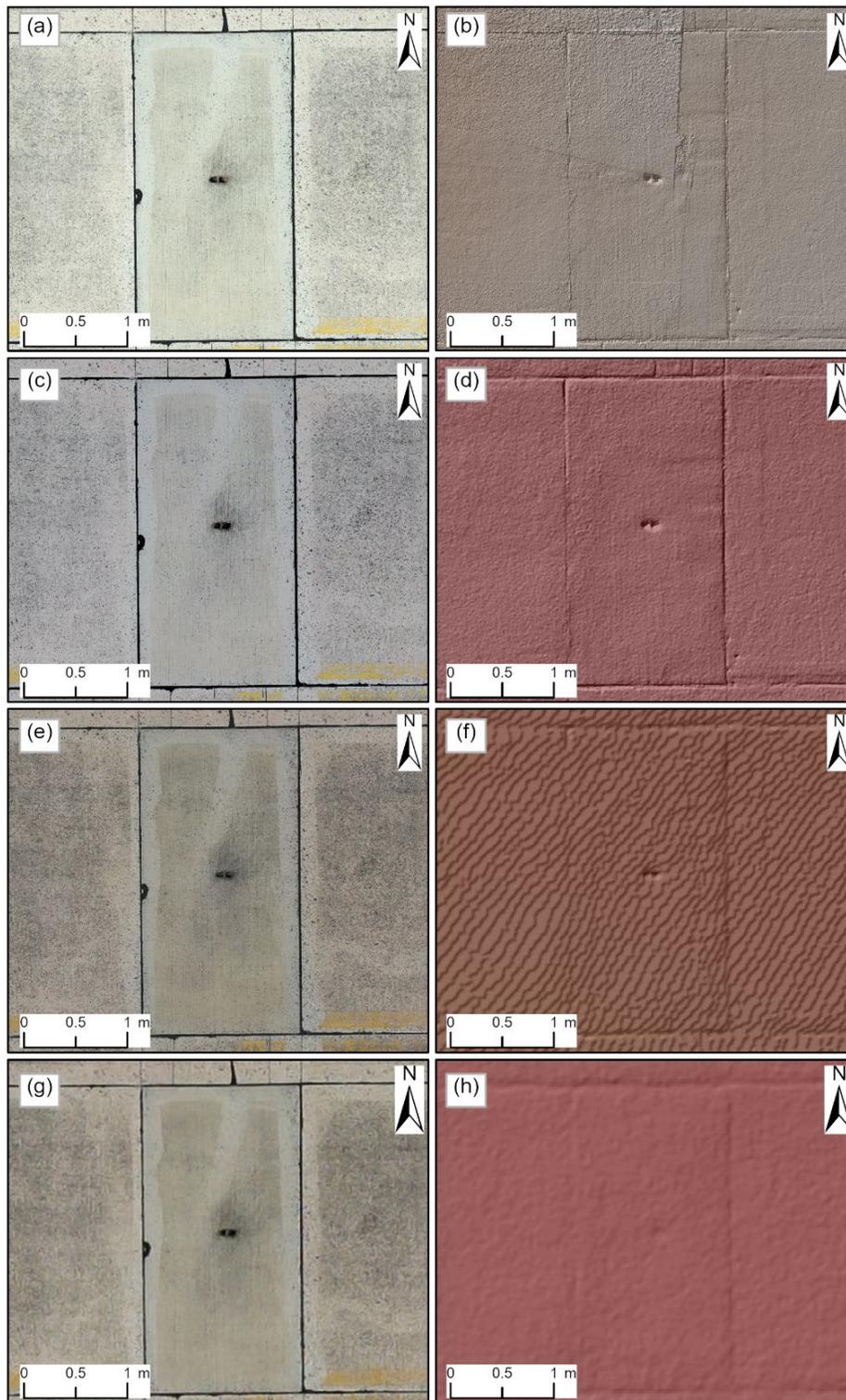


Figure 80. Low-severity Large Patching in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

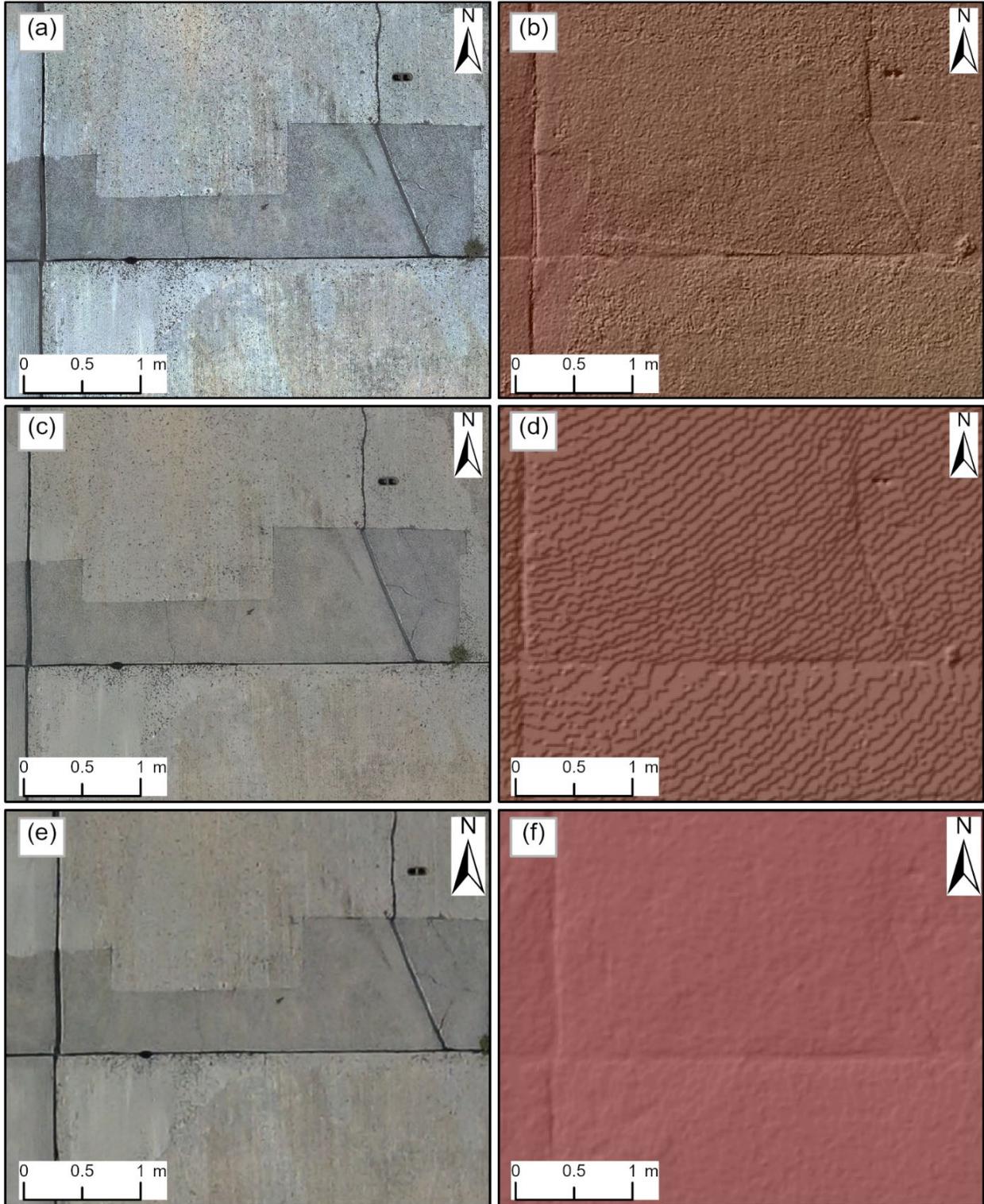


Figure 81. Medium-severity Large Patching in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

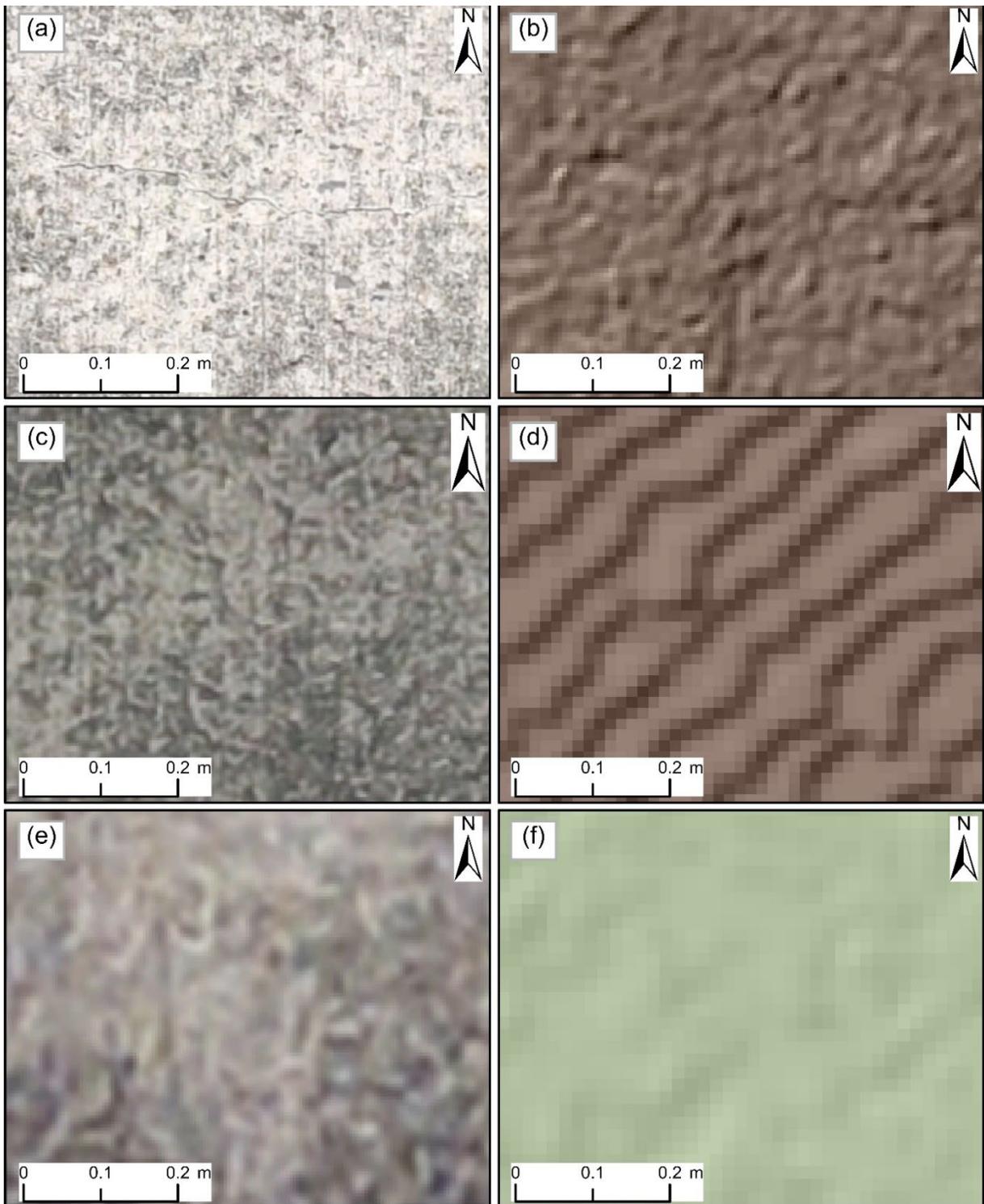


Figure 82. Shrinkage Cracks in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

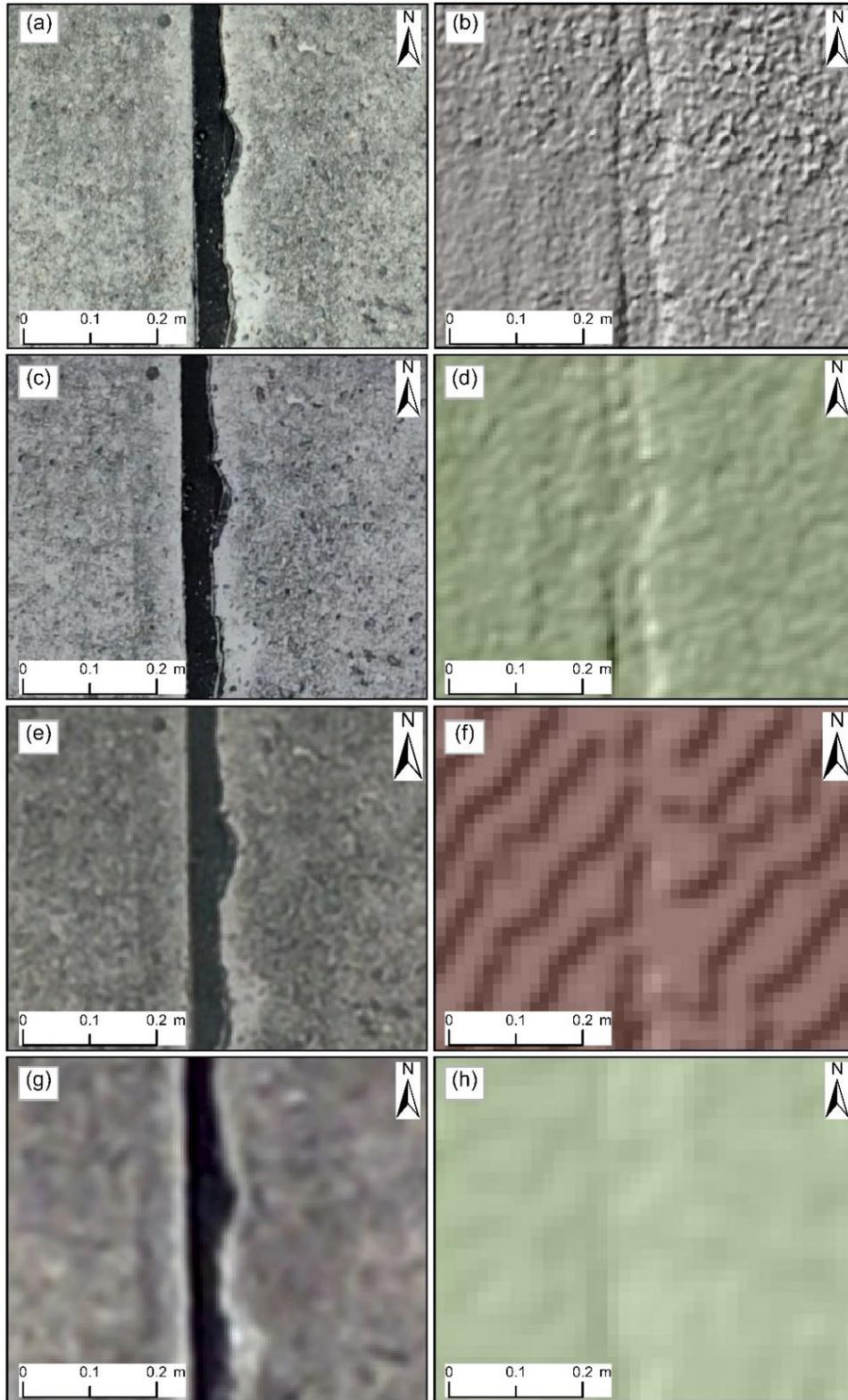


Figure 83. Low-severity Joint Spalling in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

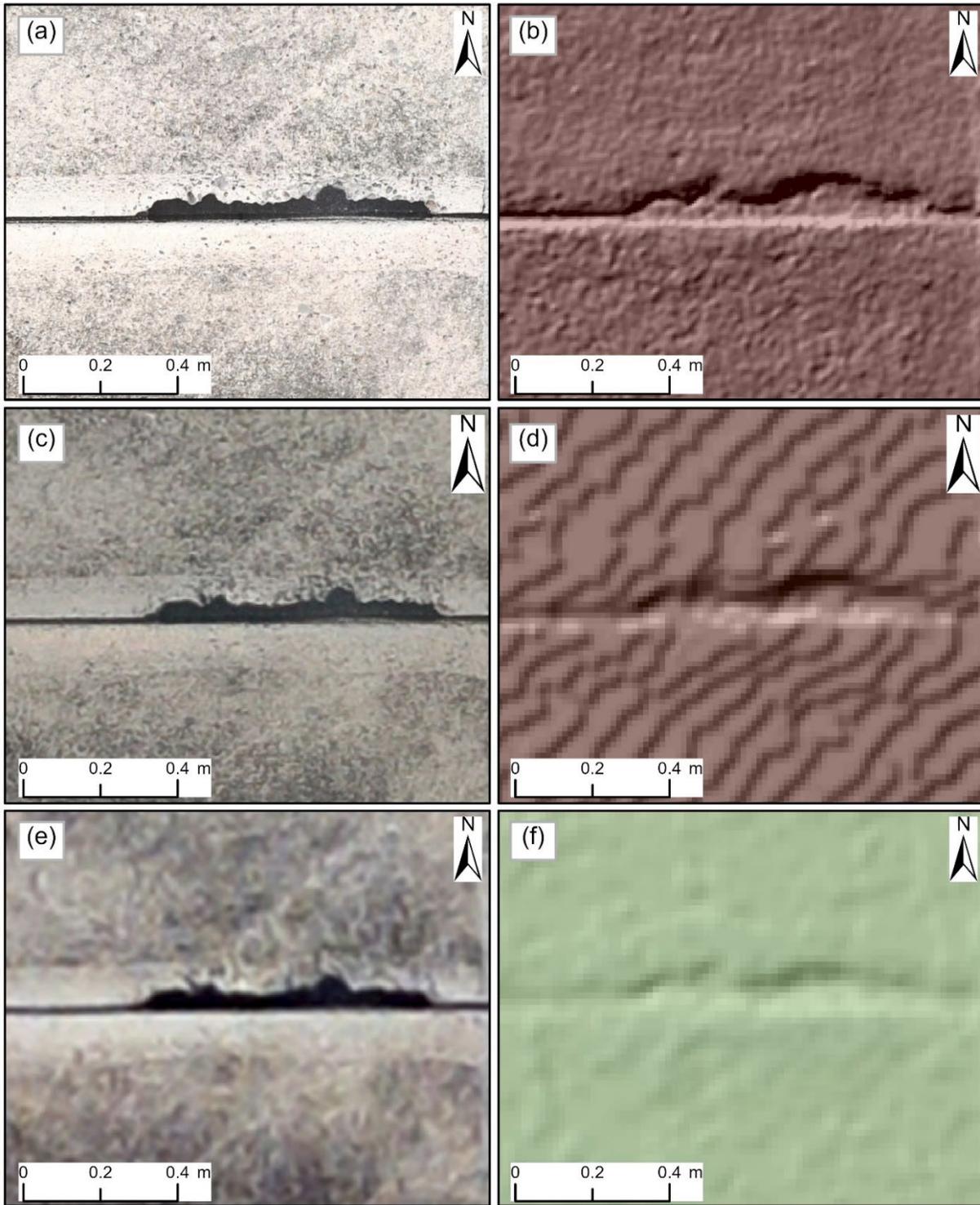


Figure 84. Medium-severity Joint spalling in (a) 1.5-mm/pix Orthophoto, (b) 5.9-mm/pix DEM, (c) 3.5-mm/pix Orthophoto, (d) 14-mm/pix DEM, (e) 4.1-mm/pix Orthophoto, and (f) 16.2-mm/pix DEM

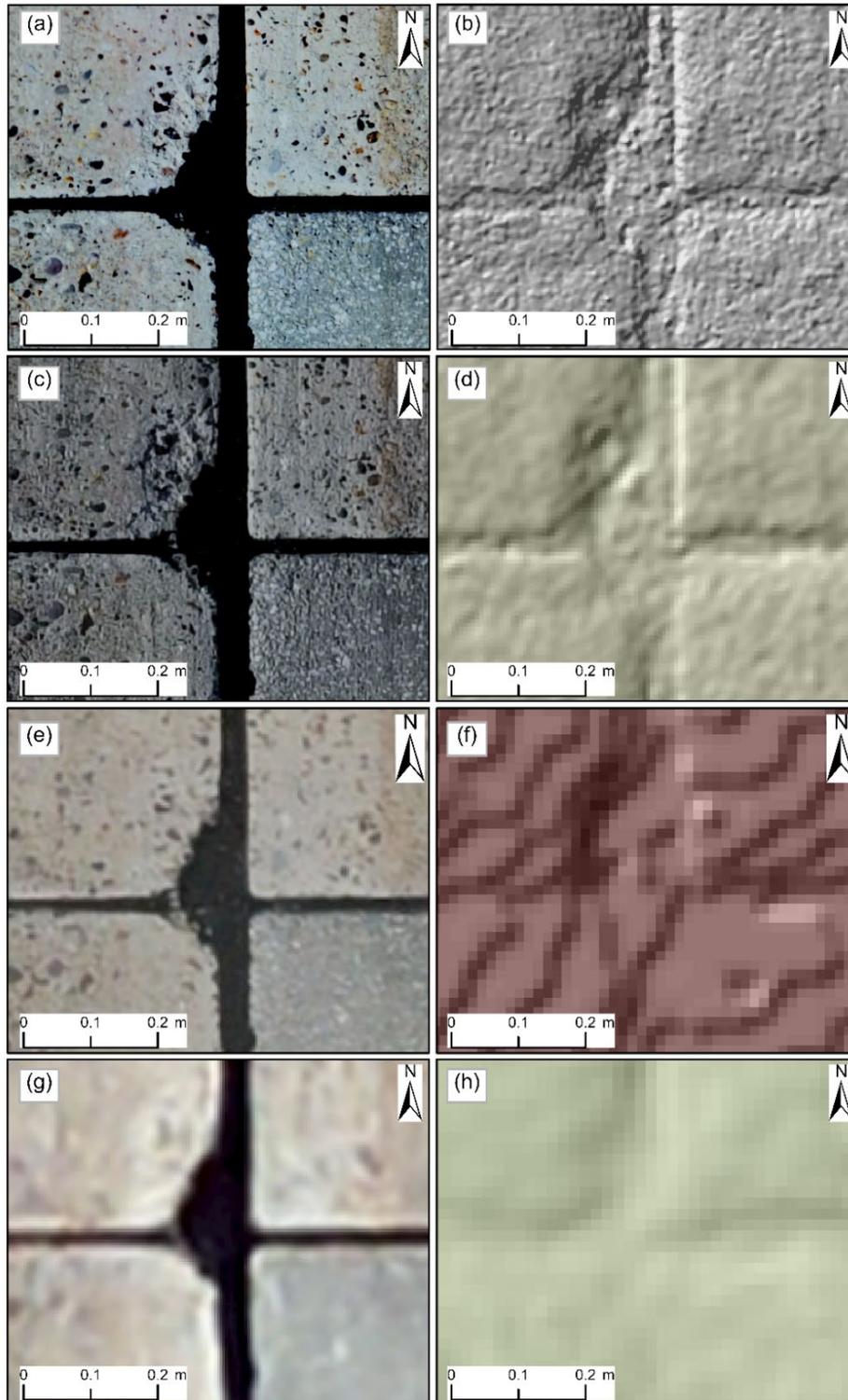


Figure 85. Low-severity Corner Spalling in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

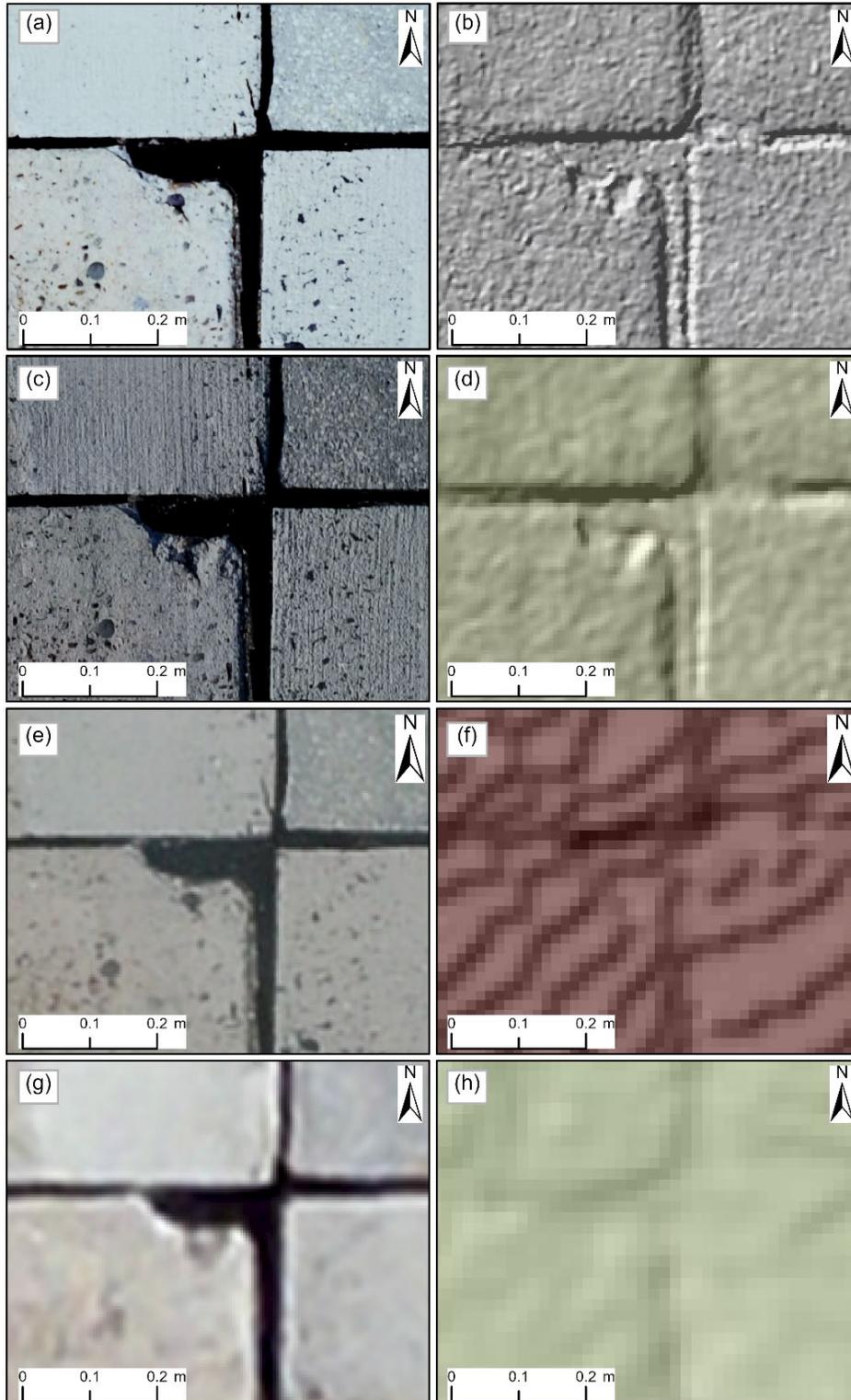


Figure 86. Medium-severity Corner Spalling in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

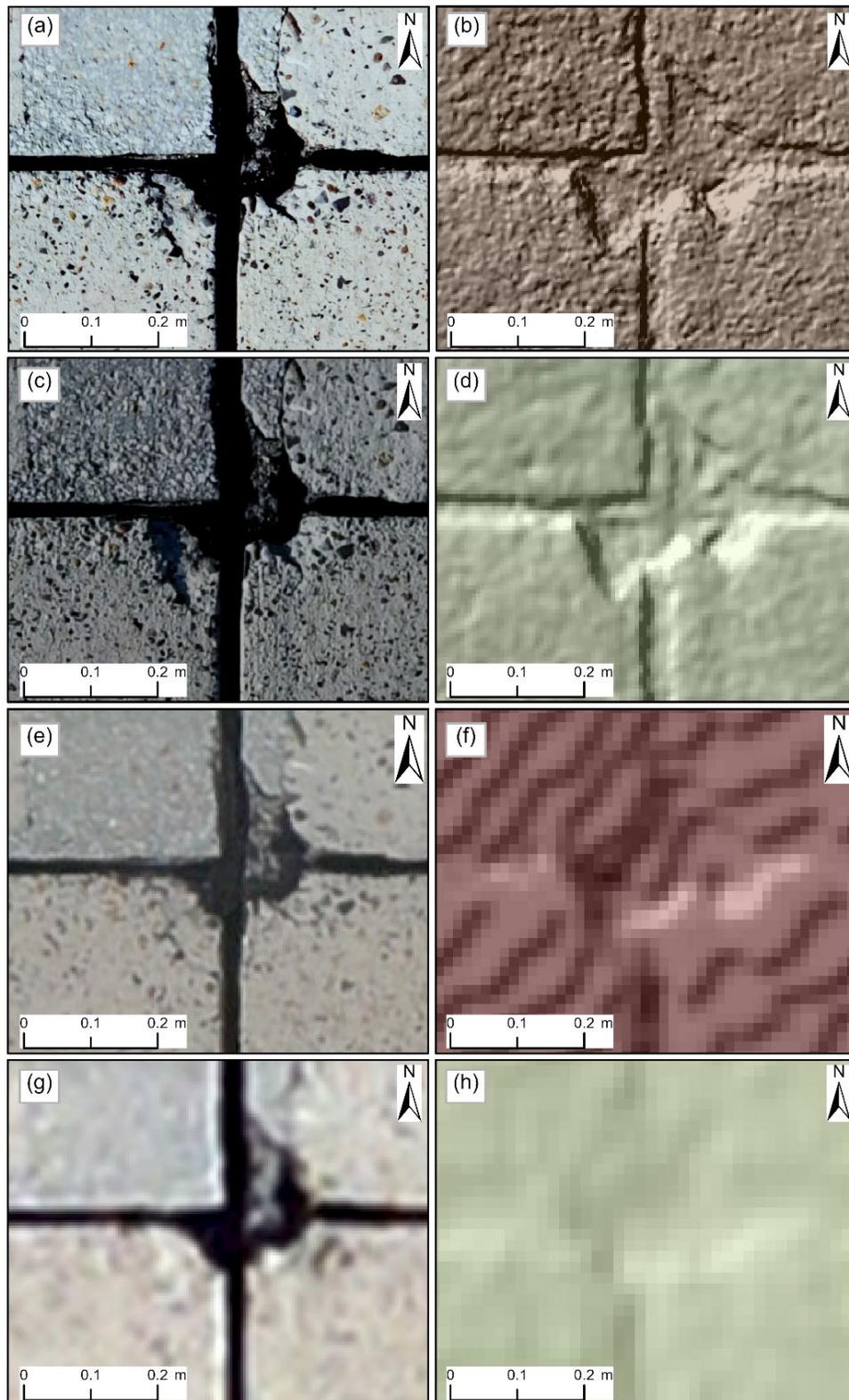


Figure 87. High-severity Corner Spalling in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

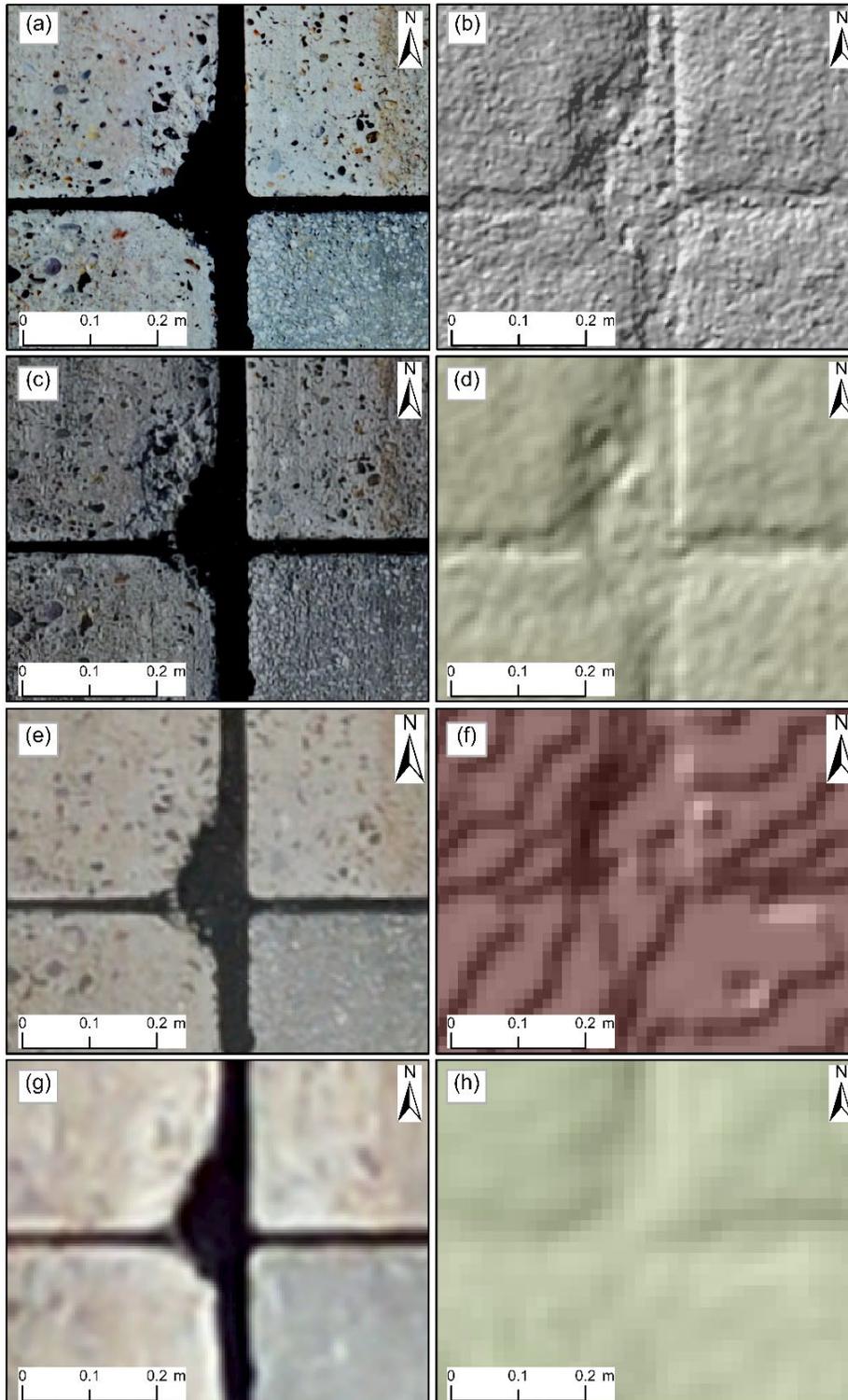


Figure 88. Low-severity ASR in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

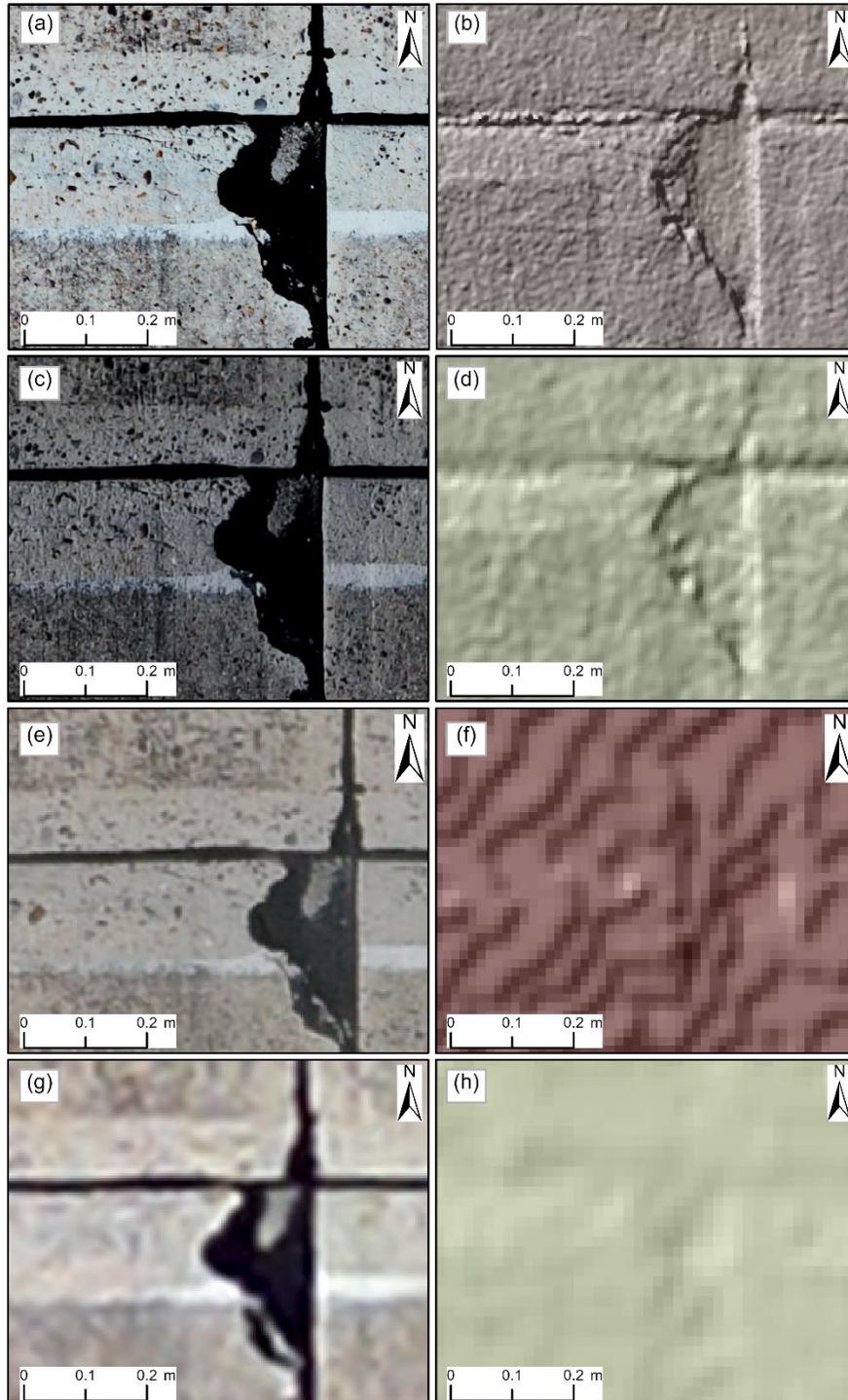


Figure 89. Medium-severity ASR in (a) 0.7-mm/pix Orthophoto, (b) 2.7-mm/pix DEM, (c) 1.5-mm/pix Orthophoto, (d) 5.9-mm/pix DEM, (e) 3.5-mm/pix Orthophoto, (f) 14-mm/pix DEM, (g) 4.1-mm/pix Orthophoto, and (h) 16.2-mm/pix DEM

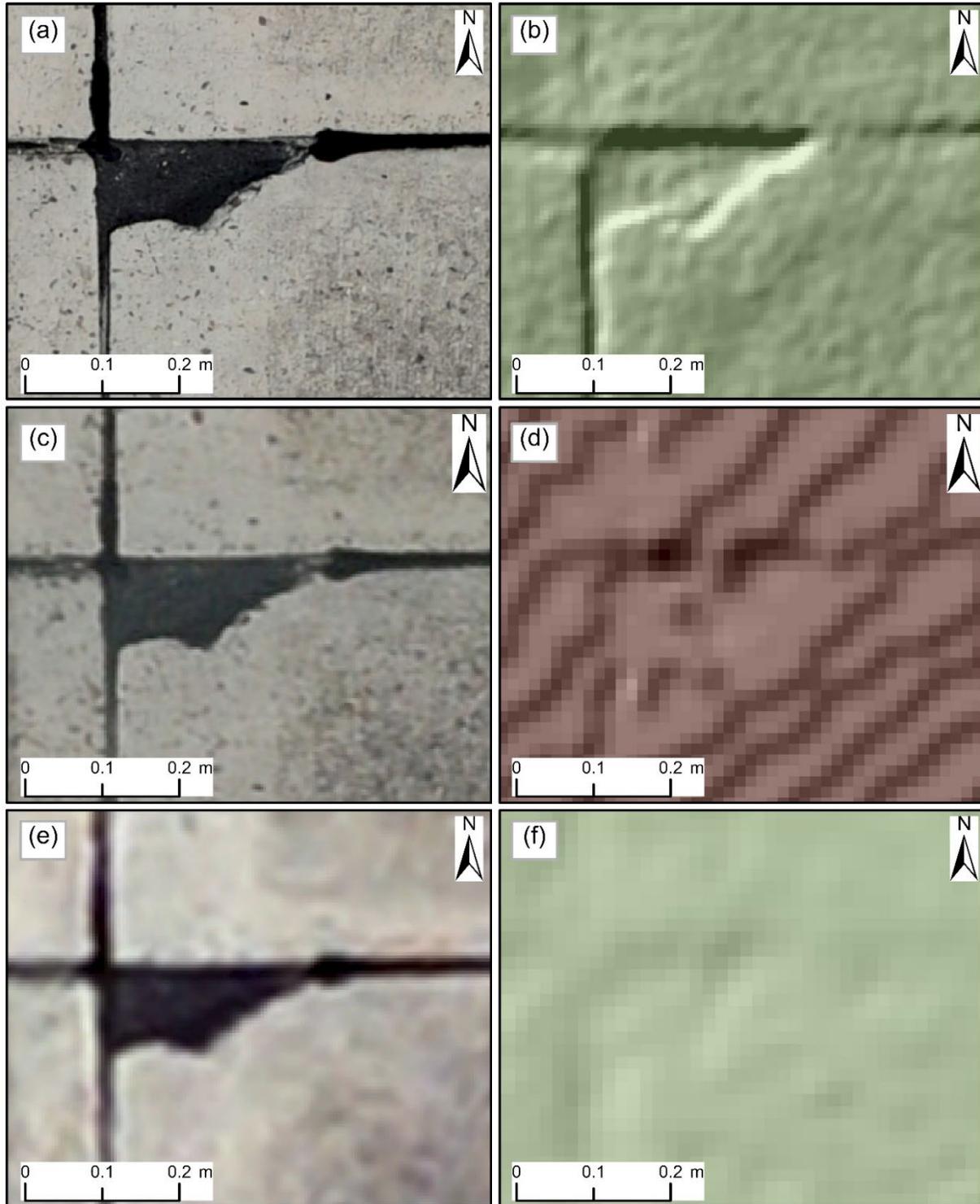


Figure 90. High-severity ASR in (a) 1.5 mm/pix Orthophoto, (b) 5.9 mm/pix DEM, (c) 3.5 mm/pix Orthophoto, (d) 14 mm/pix DEM, (e) 4.1 mm/pix Orthophoto, and (f) 16.2 mm/pix DEM

The 1.5-mm/pix RBP optical orthophoto, 5.9-mm/pix DEM, and 5.9-mm/pix DEM hillshade were imported to ArcGIS Pro for visual identification and rating of distresses present on the FBO PCC pavement section. The RGB orthophoto was mainly used for distress detection, and DEMs were used for the severity rating. Fifteen of 19 sample units on the FBO Apron Section 40, eight of nine sample units on FBO Apron Section 30, and 27 sample units on Runway 10/28 were visually analyzed. The remaining four sample units in FBO Apron either had aircraft over a large area or were missing some data. The recorded distresses were summarized and added to the FAA PAVEAIR portal to calculate the PCI value (Federal Aviation Administration, 2021b). The FOG PCI values and sUAS PCI values were plotted in Figure 91. In most cases, the sUAS based PCI values were higher than the FOG PCI calculated by APTech because of missing low-severity spalling, ASR, faulting, and shrinkage cracks. Misidentification of the severity level of spalling and ASR was also observed in multiple sample units, which includes rating low-severity distress as medium severity and vice-versa. The same phenomena were observed for AC pavement, as identification of weathering, swell, and raveling was challenging. However, raveling was identified accurately in the FBO Apron Section 30. Some of the block cracking was recorded as L&T cracks on the PCI survey, and a sUAS survey identified them as block cracking. A generic PCI survey does the same. The block cracking has been excluded from Table 14 but was considered for the sUAS-based PCI calculation.

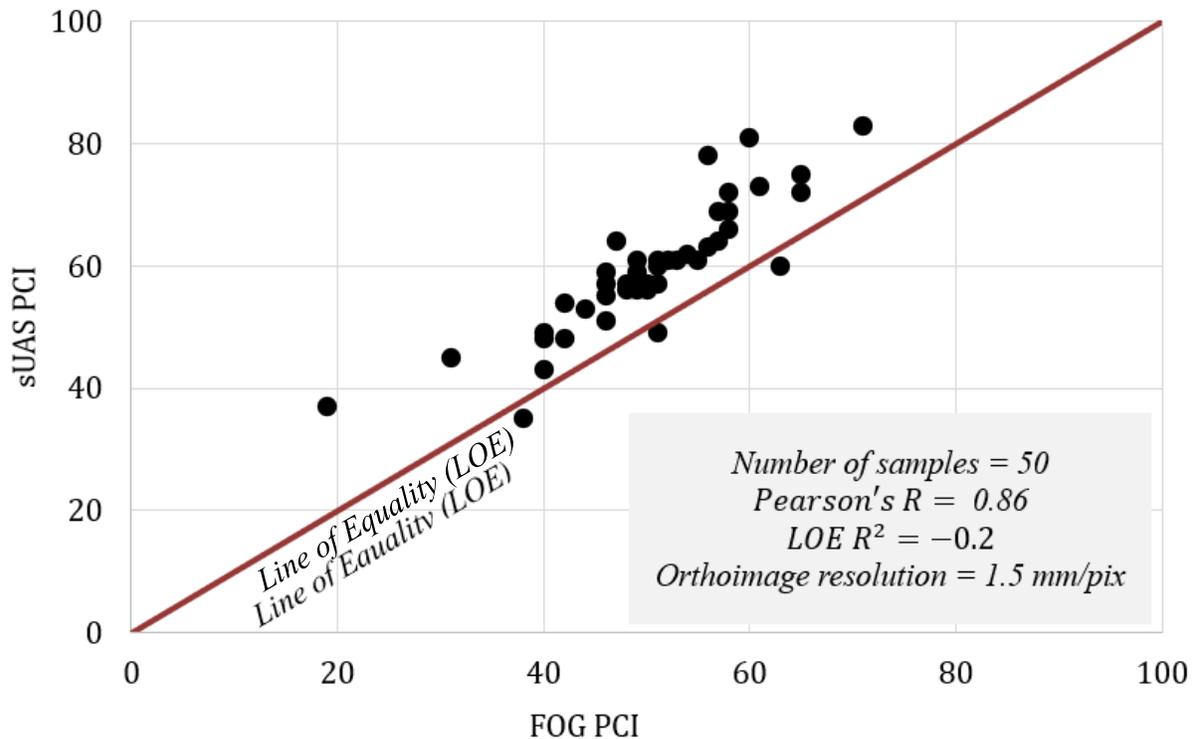


Figure 91. Foot-on-Ground PCI vs sUAS PCI Calculated Using 1.5-mm/pix Data from WWD

## 6. CONCLUSIONS

The research team executed field demonstration plans in six different airports in Michigan, Illinois, Iowa, and New Jersey. The first two field demonstrations were at Michigan airports. They were mainly focused on deploying as many Small Unmanned/Uncrewed Aircraft Systems (sUAS) as possibly available to the team at different altitudes and studying their performance in airfield pavement distress detection. As this study progressed, two new sUAS systems became available to the team and were deployed for complete data collections across remaining airports. The research team studied the performance of different sensors, data types, flight altitudes, and resolutions in detecting and rating the airfield pavement distresses.

Four data types have been studied: red-green-blue (RGB) optical orthophotos, digital elevation models (DEMs), stereo thermal orthophotos, and multispectral data. The single multispectral sensor deployed at Custer Airport (TTF) did not provide any additional value from the other three data types. The RGB optical orthophoto provided detailed visual information of Portland cement concrete (PCC) and asphalt cement concrete (AC) pavement distresses. The DEMs and thermal orthophotos also provided details of PCC and AC pavement distresses.

ASTM D5340-20 lists 16 PCC pavement distresses, and apart from blowup and pumping, 14 were available in the sUAS data collection sites in this study. The analysis showed that the RGB optical orthophotos of 3.3 millimeters (mm)/pixel or better resolution are sufficient to detect 13 of 14 PCC pavement distresses, apart from faulting, with one or more severity level(s) observed in this study. Eight AC pavement distresses were present at TTF and Coles County Memorial Airport (MTO), of 17 distresses listed by ASTM D5340-20. The analysis showed that block cracking, alligator cracking, patching, and longitudinal and transverse (L&T) cracks could be identified with RGB orthophotos.

Pavement distresses with elevation change were detected in the DEM data. The suspected location of faulting of PCC pavement and depression and shoving of AC pavement could be confirmed using high-resolution DEM. The analysis of stereo thermal data has been more limited so far, but it showed promising performance in L&T cracks of AC pavement and longitudinal, transverse, and diagonal cracks and spalling of PCC pavement detection. The L&T cracks of AC pavement underneath the pavement marking and recently overlaid with a layer of concrete showed different heat signatures than other sections of the AC pavement. The research team has planned to study the capabilities of stereo thermal data in greater detail.

Several sensors were deployed at different flight altitudes to get data with different resolutions. Based on the analysis of the sUAS data, the following resolutions are recommended:

- Any sUAS system producing an orthophoto with resolutions smaller than (better than) 5 mm/pix can detect and rate at least some distresses. This resolution excludes the orthophoto generated from data collected using Quad Bayer optical RGB sensors interpolating 12-megapixel (mp) images to 48-mp outputs. Resolutions smaller/better than 2 mm/pix produce the best data for identifying and rating the largest number of distresses. The 1.5-mm/pix orthophoto and 6.0-mm/pix DEM combination was found to be the best resolution in terms of data collection and processing time and visual details.

- Any sUAS system producing a DEM and stereo thermal orthophoto with resolutions smaller than (better than) 20 mm/pix and 30 mm/pix, respectively, are likely to be useful for distress detection and rating.
- Adequate spatial alignment of the pavement condition index survey and sUAS data, within 0.5 m or better, is very useful when visualization and evaluation of the pavement distress survey data with sUAS data are needed, and when comparing datasets from different groups that collected data at the same airports.

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APPENDIX A—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN  
FOR GROSSE ILE MUNICIPAL AIRPORT, GROSS ILE TOWNSHIP, MICHIGAN IN  
DECEMBER 2020

This small Unmanned Aerial System (sUAS) data collection plan was developed to safely collect data from Grosse Ile Municipal Airport (ONZ). This document was developed along with the safety plan provided in Appendix B.

Data Collection Date: December 10 and 11, 2020

A.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro (both) with spare batteries [charged]
  - Controller [charged]
  - Integrated controller [charged]
  - Spare 4G Pixel™ phone as a backup controller [charged]
- Bergen Hexacopter with spare batteries [charged]
  - Controller [charged]
  - Thermal camera (FLIR Vue Pro R) [batteries charged]
  - Optical camera (Nikon D850) [batteries charged]

A.2 OTHER EQUIPMENT

- Micro-SD cards/spare micro-SD cards with SD card adapter [past data stored/removed]
- Folding takeoff pad
- Generator and gas can (Michigan Tech Research Institute's (MTRI))
- Trimble Global Positioning Systems (GPS) unit with decimeter accuracy (MTRI) [charged]
- Ground control targets (eight from MTRI, up to eight from Michigan DOT)
- Ground control target nails (to keep GCPs in place)
- Rugged GPS camera (for field photos (1) [charged])
- Sony Alpha camera for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least 2 copies)
- Sporty's® SP-400 aviation radio, tuned to ONZ Unicom frequency 123.00 for the entire time the team is onsite at ONZ.
- MTRI anemometer
- Rugged Dell tablet with ArcGIS/ArcMap and Geographic Information System (GIS) data for airport data
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Tools and tape
- High-visibility vests, hardhats, and protective eyewear

- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of MTRI safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher
- Bottled water

All batteries will be charged, and equipment packed and placed in the MTRI GIS laboratory the day before field collection (i.e., on Tuesday, December 8, 2020).

### A.3 FOCUS AREAS FOR DATA COLLECTION

The focus is on Runway 17/35 and Taxiway A (TWAGI-10) because their condition is relatively worse than other airport features, and these feature types appear to be of higher priority to the FAA. Runway section RW1735GI-10, with a Portland cement concrete (PCC) surface, has a pavement condition index (PCI) of 49 (57 in 2017), with seven types of distress and seven inspected sample units in the most recent inspection (from October 2020), with sample units 3, 5, 8, 12, 14, 17, and 20 having been inspected with a total area of 3121.5 square m. RW1735GI-20 with PCC surface has a PCI of 40, with 7 distresses and 13 inspected sample units totaling 5797.2 square m, with sample units 5, 14, 23, 31, 40, 49, 58, 67, 76, 85, 94, 102, and 112 having been inspected. TWAGI-10 has a PCI of 40, with 8 distress types and 10 inspected sample units totaling 1858 square m. The total area of Runway 17/35 is 31789.6 square m (4698.9 square m for section 10 and 27094.7 square m for section 20), with a total runway length of 1348.4 m. TWAGI-10 is approximately 1019.9 m. See Figure A-1 for an overview of these areas.

Within Runway 17/35 and Taxiway A, the priority is to collect data at a subset of the sampling units to demonstrate the initial feasibility of drone-enabled airport pavement inspection and prepare for a more detailed follow-up sUAS survey in early 2021. Table A-1 lists the distresses known to occur at ONZ, based on the 2017 survey.



Figure A-1. Overview of ONZ with CAD Data Displayed over 2020 NAIP Image

Table A-1. Pavement Distress Summary of ONZ (MDOT, 2018)

Facility	Section	Age (yr)	Surface Type	2018/2021 PCI	Distresses
Apron	10	51	PCC	46	ASR (L, M, H), corner break (M), corner spalling (L, M, H), faulting (L, M), joint seal damage (H), joint spalling (M, H), LTD cracking (L, M), shattered slab (M), small patching (H)
	20	13	PCC	64	Faulting (L), joint seal damage (H), large patching, LTD cracking (L, M), joint spalling (H), shrinkage cracking
Taxiway A	10	24	PCC	40	ASR (L, M), blow-up (L, M), corner break (L, M, H), faulting (L), joint seal damage (H), large patching (L, M, H), LTD cracking (L, M), shattered slab (L, M, H)
Taxiway C	10	13	PCC	90	ASR (L), corner spalling (L, M), joint seal damage (M, H), blow-ups (L), large patching (L), joint spalling (M)
	20	16	PCC	79	ASR (L, M), corner break (M), corner spalling (L, M, H), joint seal damage (M), joint spalling (M), LTD cracking (L, M), joint spalling (M)
T-hangar	10	34	PCC	43	ASR (H), corner break (L, H), corner spalling (L, M), faulting (L, M), joint seal damage (H), joint spalling (L, M, H), large patching (L), LTD cracking (L, M), shattered slab (M, H), shrinkage cracking
	20	21	PCC	17	ASR (L, M), corner break (H), corner spalling (H), joint seal damage (H), LTD cracking (L, M, H), shattered slab (M)
Runway 4/22	10	5	AC	99	L&T cracking (L)

L = Low severity, M = Medium severity, H = High severity  
 AC = Asphalt concrete pavement  
 PCC= Portland cement concrete pavement  
 PCI = Pavement Condition Index  
 ASR = Alkali silica reaction  
 L&T Cracking = Longitudinal and transverse cracking  
 LTD cracking = Longitudinal, transverse, and diagonal cracking

Table A-1. Pavement Distress Summary of ONZ (MDOT, 2018) (Continued)

Facility	Section	Age (yr)	Surface Type	2018/2021 PCI	Distresses
Runway 17/35	10*	20	PCC	34	ASR (L, M), corner break (H), scaling (M), faulting (L, M), joint seal damage (H), LTD cracking (L, M)
Runway 17/35	20*	21	PCC	33	ASR (L, M), corner break (L, M), scaling (M), faulting (M), joint seal damage (M, H), LTD cracking (L, M), large patch (L, M, H), durability cracking (L, M, H), shattered slab (M)
Runway 17/35	10	20	PCC	57	ASR (L, M), corner break (L), corner spalling (L), scaling (L), faulting (L, M), joint seal damage (MH), LTD cracking (L)
	20	21	PCC	40	ASR (L, M), corner break (M), D-cracking (L, M, H), faulting (H), joint seal damage (M, H), Large patch (L), LTD cracking (L, M)

L = Low-severity, M = Medium-severity, H = High-severity

AC = Asphalt concrete pavement

ASR = Alkali silica reaction

PCI = Pavement Condition Index

L&T cracking = Longitudinal and transverse cracking

LTD cracking = Longitudinal, transverse, and diagonal cracking

\*Data collected in 2021 as part of this study

With the detailed 2020 survey results currently being processed, the 2017 inspection results help to focus on particular sampling units. In 2017, RW1735GI-10 had alkali-silica reaction (ASR) at sample unit 03 and longitudinal, transverse, and diagonal cracking (LTD) cracking at sample unit 5. RW1735GI-20 had durability cracking at 5 and 23, and large patching at 23. The focus will be on four runway sample units because these specific distresses occurred here in 2017 and have probably only gotten worse since then. For TWAGI-10, ASR occurred at sample unit 15, blowup and shattered slab at sample unit 25. The focus will be on these two sample units because these distresses occurred at these specific locations in 2017. Figure A-2 highlights these priority sample units for the December 2021 sUAS data collection. Table A-2 lists the distresses recently surveyed at these six sample units based on the recent October 2020 survey by APTEch (updated with PCI inspection conducted in January 2021).

Two flights will capture all of Runway 17/35, and two will capture all of TWAGI-10. Each area has flights occurring at different heights to help evaluate how different resulting resolutions may help identify particular distresses while allowing for rapid data collection.

Table A-2. The PCI Distress Summaries of Selected Sample Units

Sample Unit	Distress ID	Distress Name	Sample Unit	Distress ID	Distress Name	
RW1735 GI-10 SU 3	62	Corner break	RW1735 GI-20 SU 23	63	L&T cracking	
	63	L&T cracking		64	Durability cracking	
	65	Joint seal damage		65	Joint seal damage	
	71	Corner spalling		67	Large patch	
	76	ASR		71	Corner spalling	
RW1735 GI-10 SU 5	63	L&T cracking		72	Shattered slab	
	65	Joint seal damage		76	ASR	
	70	Scaling		TWAHI-10 SU 15	63	L&T cracking
	71	Corner spalling			64	Durability cracking
	76	ASR			65	Joint seal damage
		76	ASR			
RW1735 GI-20 SU 5	63	L&T cracking	TWAHI-10 SU 25	64	Durability cracking	
	64	Durability cracking		65	Joint seal damage	
	65	Joint seal damage		76	ASR	
	76	ASR				

RW1735 = Runway17/35

RW1735 GI-10 = Runway 17/35 section 10

RW1735 GI-20 = Runway 17/35 section 20

TWAHI-10 = Taxiway A section 10

SU = Sample unit

ASR = Alkali-silica reaction

L&T cracking = Longitudinal and transverse cracking



Figure A-2. Focus Area for Data Collection with Six Selected Priority Sample Units Highlighted

## A.4 OBJECTIVES FOR WEDNESDAY 12/09/2020 DRONE DATA COLLECTION

### A.4.1 DJI Mavic 2 Pro

DJI Mavic 2 Pro optical imagery will be collected over Runway 17/35 and Taxiway A. A total of four flights is necessary to cover two separate altitudes (91.4 m and 30.5 m). The planned flights with the DJI Mavic 2 Pro are:

#### **Runway 17/35**

- 91.4 m AGL flight will collect 21 mm/pix (0.8 in/pix) resolution imagery and require an estimated 12 minutes to complete (one flight).
- 30.5 m AGL flight will collect 7 mm (0.3 in/pix) resolution imagery and require an estimated 22 minutes to complete (one flight).

#### **Taxiway A**

- 91.4 m AGL flight will collect 21 mm/pix (0.8 in/pix) resolution imagery and require an estimated 10 minutes to complete (one flight).
- 30.5 m AGL flight will collect 7 mm (0.3 in/pix) resolution imagery and require an estimated 20 minutes to complete (one flight).

Flights made over Taxiway A may be shortened to cover only the western part due to aircraft traffic on Runway 4/22 approaching the Taxiway. The reduced flights will occur between Runway 17/35 and Taxiway C if needed.

The flight plans for these missions were completed with the Pix4D Capture Android application. An 80% forward overlap and a 70% side overlap are used, standard for most missions where close-range photogrammetry software is used to create orthophotos and digital elevation model (DEM) outputs. The 30.5 m and 91.4 m heights were selected as representative heights for demonstrating different resolutions for output products and their potential for distress detection. These heights were found to be useful for previous lower- and higher-resolution geospatial output products, depending on particular project needs. Figure A-3 shows an example of the flight area planned for the Runway 17/35 flights at 31 m elevation. Figure A-4 shows a part of that flight plan with the need for three flight lines when flying around 30.5 m elevation. Figure A-5 shows only two flight lines when flying at around 91.4 m elevation. The “Too Large” message is from a known bug in the Android version where the application incorrectly tells the user the data-collection area may be too large to maintain communications with the drone (this was not the case here).

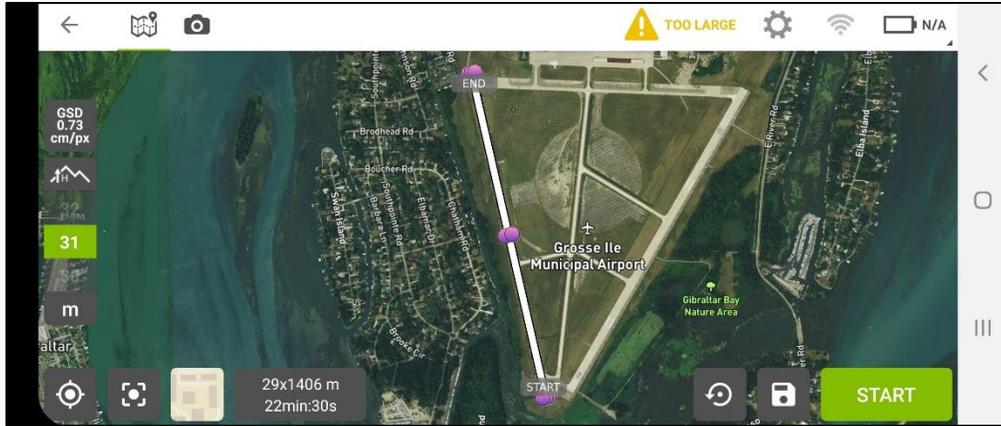


Figure A-3. Example Flight Plan Area for the Runway 17/35 Mission Taking Place at 30.5 m, Requiring 22:30 Minutes of Flight Time with the DJI Mavic 2 Pro



Figure A-4. Example North End of the Runway 17/35 Mission Plan Taking Place at 30.5 m, Requiring Three Flight Lines (white lines within a yellow polygon)



Figure A-5. Example North End of the Runway 17/35 Mission Plan Taking Place at 91.4 m, Requiring Two Flight Lines (white lines within yellow polygons)

#### A.4.2 Bergen Hexacopter

The Bergen Hexacopter will be flown manually to collect high-resolution optical and thermal overhead imagery from an altitude of 9.1 m over the preselected sample units of Runway 17/35 and Taxiway A for detailed surveys. These sample units are mostly 9.1 m x 53.4 m at ONZ, equal to 487.7 square m. A total of six flights (three optical and three thermal) are required to cover the four sites on Runway 17/35 and two sites on Taxiway A because some sample units are near each other and can be covered in a single flight. Sample units 3 and 5 for RW1735GI-10 will be completed as a pair in one flight; sample units 5 and 23 for RW1735GI-20 will be completed as a pair; and sample units 15 and 25 for TWAGI-10 will be completed as a pair. Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired sample units are. The estimated optical imagery will have a 1-mm resolution, whereas the thermal imagery will be 8 mm. Based on experience, the 9.14-m height was selected as a representative height useful for higher-resolution 3D data creation. Manual control is planned because of the small areas planned for data collection and because the older flight control software is not compatible with current mission-planning applications.

#### A.5 PILOTS AND SUPPORT TEAM

The Michigan Tech team has four research staff available for this project, all of whom have a current Part 107 Unmanned Pilot's Certificate. Standard procedure is to have at least two staff members for sUAS flights: one sUAS pilot and one safety observer. Because this is the first deployment for this project, the plan is to bring all four staff members, which will help establish a common experience for airport data collection for this project.

*Provisional timeline for December 9 (December 10 only planned if necessary, planning on finishing all data collection on 12/9)—All timing is subject to change!*

The entire half-hour block of time allocated to each drone flight is not required to complete data collection. There is planned downtime to accommodate battery/sensor swaps and to remain grounded while aircraft operate in the vicinity. The data-collection team will have their aviation radio on at all times for data collections on Unicom frequency 123.00 used for ONZ. Windows of moving vehicles will be kept open, with car radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection on the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends (305 m, 333 yards) will be used, and the team will stay outside these areas when not completing a data collection. They will remain 76.2 m horizontally away from any moving aircraft. They will not operate sUAS if wind gusts exceed 24 kmph or are predicted to be more than 24 kmph 24 hours ahead of the data collection times. A handheld anemometer will be used to measure wind speed before each mission.

Below is the planned data collection timeline:

- 9:00 – 10:00: Set ground control targets and collect Trimble decimeter-level GPS data for GCPs for Runway 17/35.
- 10:00 – 10:30: Collect Bergen Hexacopter Thermal imagery of four sample units on Runway 17/35 at 9.1 m AGL.
- 10:00 – 11:00: Set ground control targets and collect Trimble decimeter-level GPS data for GCPs for Taxiway A.
- 11:00 – 11:30: Collect Bergen Hexacopter thermal imagery of two sites on Taxiway A at 9.1 m AGL.
- 12:00 – 12:30: Collect DJI Mavic 2 Pro imagery of both Runway 17/35 and Taxiway A at 91.4 m AGL.
- 12:30 – 13:00: Collect DJI Mavic 2 Pro imagery of Runway 17/35 at 30.5 m AGL.
- 13:30 – 14:00: Collect DJI Mavic 2 Pro imagery of Taxiway A at 30.5 m AGL.
- 14:30 – 15:00: Collect Bergen Hexacopter high-resolution optical imagery of four sites on Runway 17/35 at 9.1 m AGL.
- 15:00 – 15:30: Collect Bergen Hexacopter high-resolution optical imagery of two sites on Taxiway A at 9.1 m AGL.
- 15:30 – 16:00: Recover ground control targets.

All missions will be documented by a photographer designated for each mission, from one of the Michigan Tech staff, not flying the sUAS or acting as an observer.

#### A.6 REFERENCES

MDOT. (2018). *Grosse Ile Municipal Airport Pavement Management Report*.

APPENDIX B—AIRPORT CONDITION SURVEY SAFETY PLAN FOR GROSSE ILE MUNICIPAL AIRPORT, GROSS ILE TOWNSHIP, MICHIGAN IN DECEMBER 2020

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Grosse Ile Municipal Airport (ONZ). This document was developed along with the data collection plan provided in Appendix A. Figures B-1 and B-2 show the travel plans for the research team, whereas Figure B-3 highlights ONZ layout and location of the ground control points (GCPs).

Data Collection Date: December 10 and 11, 2020

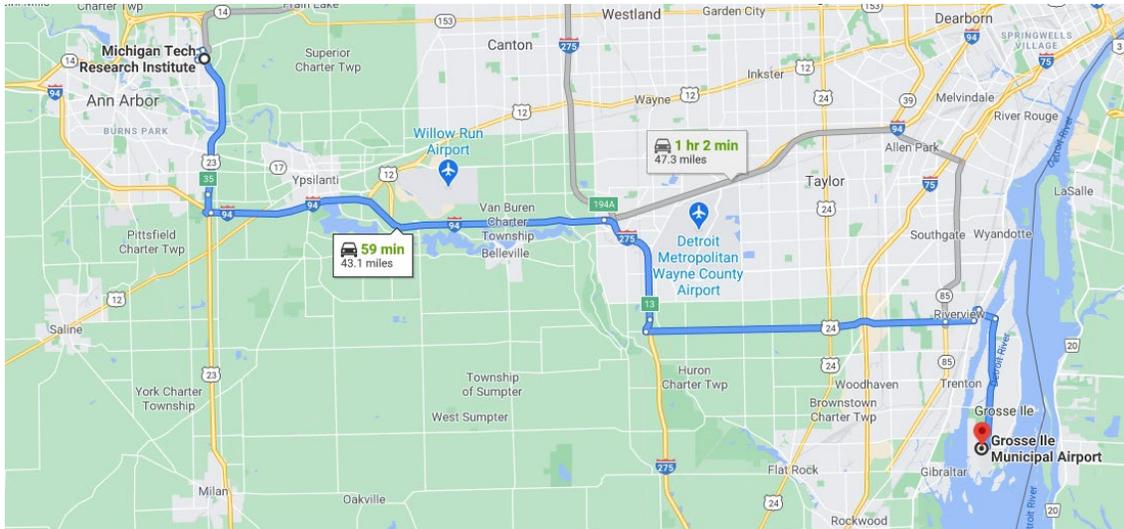


Figure B-1. Travel Route from Ann Arbor, Michigan to Grosse Ile, Michigan

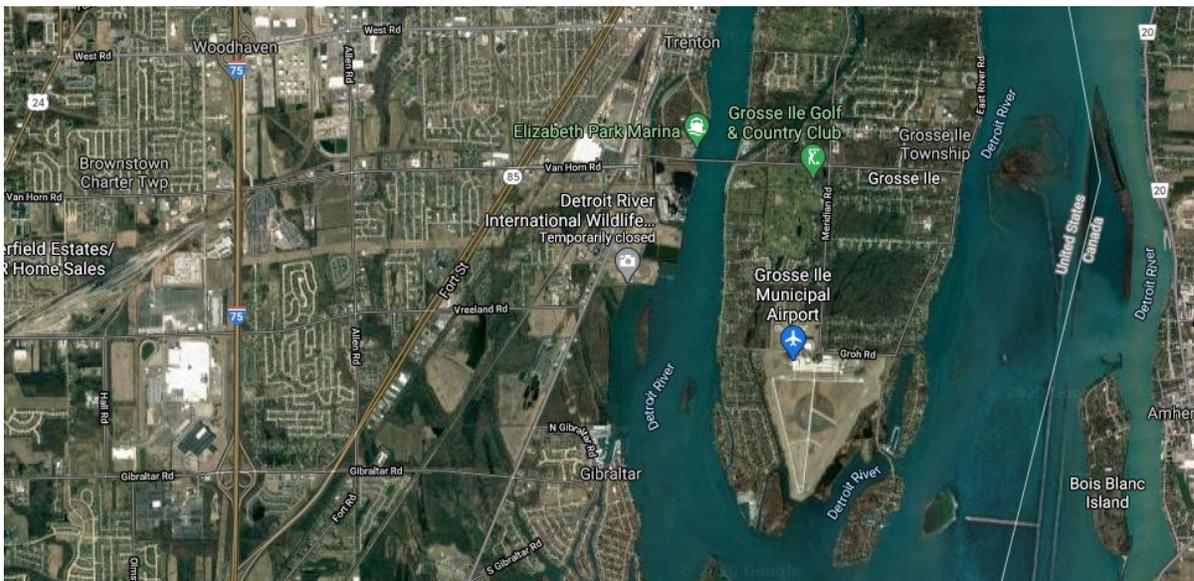


Figure B-2. View of the Grosse Ile Municipal Airport (ONZ), Michigan

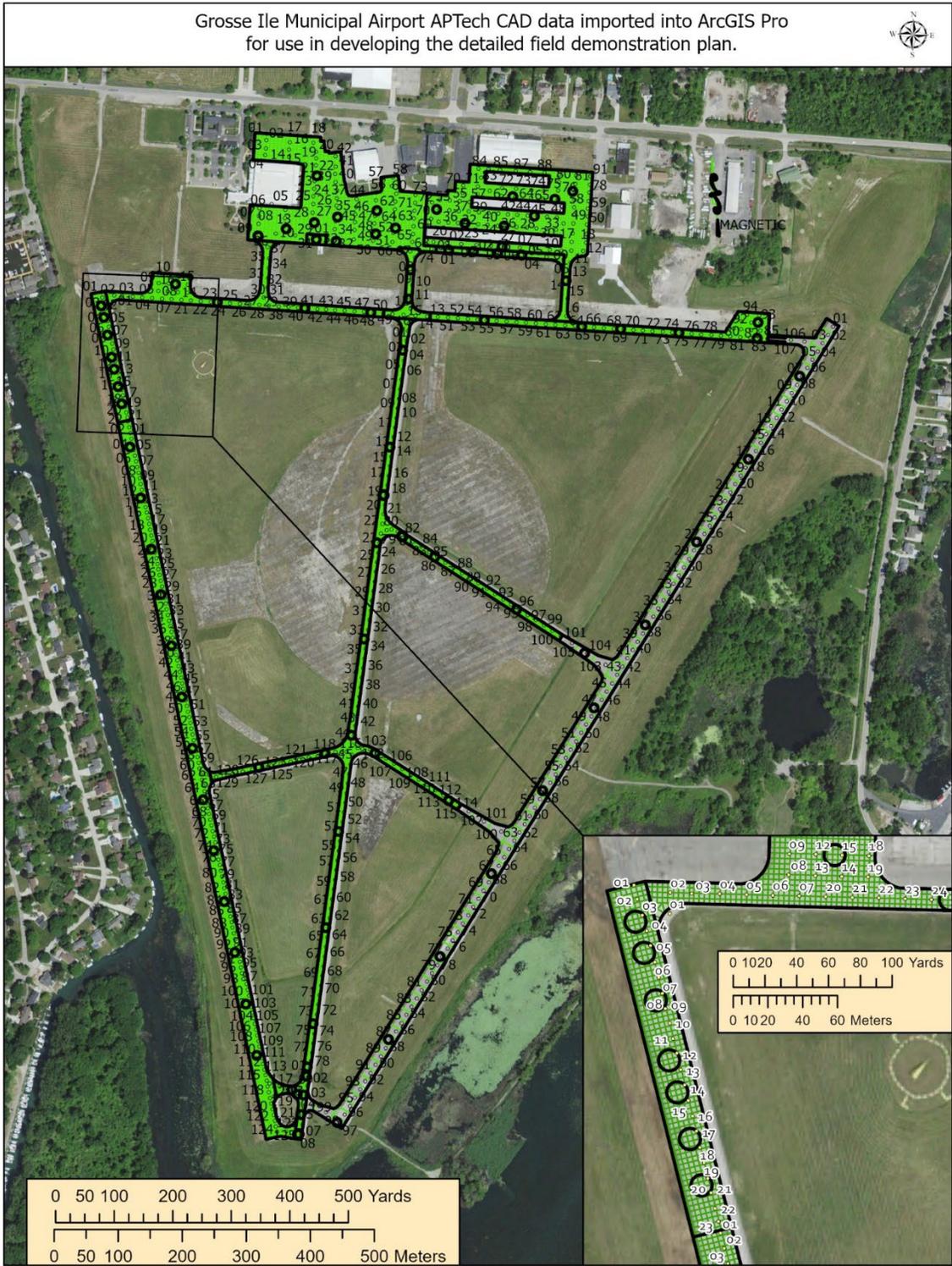


Figure B-3. Location of the Ground Control Points

## B.1 CONTACT INFORMATION

For any safety questions during field data collection, please contact:

- Colin Brooks (Principal Investigator [PI] and Data collection lead)
- Richard Dobson (Lead pilot-in-command)

Other participants are:

- Chris Cook (Road and drone safety observer, backup pilot)
- Ben Hart (Additional pilot, sensor expert)

Proposed schedule:

Depart Michigan Tech Research Institute (MTRI) at 7:30 a.m., arriving at ONZ at approximately 8:30 a.m. (travel time to ONZ from MTRI is approximately 1 hour). Survey the airport area, pack up, and head home at approximately 4 to 5 p.m.

## B.2 FIELD SITE

ONZ near Grosse Ile Township, Michigan. The airport manager at ONZ is Michael Duker, who has agreed to UAS field deployment. He will be issuing a Notice to Airmen (NOTAM) for airport operations, now planned for Thursday, December 10, 2020.

## B.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on a hard hat and reflective vest. Driving vehicles must have yellow caution lights present. Additionally, the requirements listed below will be followed.

- All crew members on the field site must be wearing protective clothing (hardhat, steel- or composite-toe boots, high-visibility vest, and glasses) at all times.
- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic, and for the safety of the pilot. The spotter will control the aviation radio and have the option of sharing control with an additional crew member.
- Crew members will adhere to a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway or taxiway being surveyed by UAS, operations will cease and continue only after the aircraft have finished their take off or land procedures.
- The data collection team will have their Sporty's® 400 aviation radio on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 123.00 used for ONZ. Windows of moving vehicles will be kept open, with car radios off, to enable listening for unexpected aircraft when driving on runways and taxiways.
- Crew members will not stand in open traffic lanes. If walking along an open stretch of roadway, crew members will walk against the flow.

- Crew members must always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members will stand on runways or taxiways only during data collections, if needed.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the ends of the runway will be used, so stay outside these areas when not completing a data collection. Will keep 76.2 m horizontally from any moving aircraft.

#### B.4 sUAS SAFETY

The pilot-in-command (Richard Dobson) will brief all participants a day prior to field collections of where the UAV will be operating, safe places and minimum distance to stand or work while the UAV is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a Remote Pilots Certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified pilots may fly. Additional safety requirements are listed below.

- Remain a safe distance from, and do not stand directly below, a flying drone.
- DO NOT attempt to distract the pilot or designated spotters while the UAVs are being operated unless it is an immediate emergency.
- All drone operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the UAV flight path, all operations must immediately end until safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand in case of a battery fire.
- UAS will not be operated if wind gusts exceed 15 mph or are predicted to be more than 15 mph 24 hours ahead of the data-collection times. A hand-held anemometer will be used to measure wind speed before each mission.

#### B.5 FIRST AID AND MEDICAL/EMERGENCY INFORMATION

- A first aid kit will be on site with the field crew for all site visits.
- A safety briefing will be held at the beginning of the day before any operations start. All crew members are encouraged and required to share any safety concerns immediately with team lead Colin Brooks and other people as needed.
- Emergency number is 911. Call in case of emergencies. Also call the airport manager once the situation is safe: Michael Duker.
- Nearest hospital location to study site at Grosse Ile, Michigan: Beaumont Hospital, Trenton (17.7 km, 23 minutes). 5450 Fort St, Trenton, Michigan 48183 Phone: +1-734-671-3800 (non-emergency).
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead).

## B.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew will travel with hand sanitizer and use it at the beginning and end of the day and at all breaks.
- Field equipment will be individually assigned as much as possible (for example, whomever starts with a particular drone will use that one throughout the rest of the day) and will be disinfected with sanitizer wipes when possible.
- Multiple field crew may travel within the same vehicle when the University's Health and Safety Level is at Level 3. Level 3 requires a face covering for everyone when riding in a vehicle with more than one person. The vehicle must be sanitized between uses. Field crew that regularly travel/work together may sit up to two people per seat row; all others follow Level 4 guidance, which requires sitting in separate rows.
- When the University is at Level 5, as it is as of 11/30/2020, the protocol requires one person per vehicle, and they may only travel following an approved exemption, which MTRI staff can obtain.
- Note that there is a cleaning protocol in place for the MTRI Durango that MUST be followed—laminated copies can be found inside the Durango.
- Work is to comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
- Ramping Up Research Checklist: <https://docs.google.com/document/d/1llxdTZH1r0jGW8mlmetGswPdhHcy1ukbYu70AdSwNQQ/edit>
- COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
- Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
- Research Pandemic Checklist: [Research Pandemic Checklist - Google Docs](#)
- To request a travel exemption, submit a MTRI Travel Authorization through Lisa Phillips (lphillip@mtu.edu), who will contact the appropriate person on campus (currently Kathy Halvorsen - [kehalvor@mtu.edu](mailto:kehalvor@mtu.edu)) for permission.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

APPENDIX C—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN  
FOR GROSSE ILE MUNICIPAL AIRPORT, GROSS ILE TOWNSHIP, MICHIGAN,  
IN MAY 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Grosse Ile Municipal Airport (ONZ). This document was developed along with the safety plan provided in Appendix D.

Data Collection Date: May 14, 2021

C.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED EQUIPMENT

- DJI Mavic 2 Pro Enterprise Advanced with integrated dual 48-mp camera and 640 x 512 thermal camera (two camera systems—one from Michigan Tech Research Institute [MTRI], one from Iowa State University).
- Seven M2EA batteries from MTRI, six batteries from Iowa State [charged].
- Smart Controller for each drone[charged].

C.2 OTHER EQUIPMENT

- Propeller AeroPoint™ electronic Global Positioning System (GPS)-based ground control targets (10)
- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- Folding takeoff pad for Mavic 2
- Generator and gas can (MTRI's)
- Rugged Olympus Tough TG-5® GPS Camera (12 mp) (for geolocated field photos) (1) [charged]
- Sony Alpha Camera (16 mp) for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least two copies), completed with planned flights information
- Sporty's® SP-400 aviation radios (2), tuned to the correct Unicom frequency for the entire time the team is onsite. Additional aviation radio from Iowa State will be present.
- One aviation radio is for the two-person UAV flight team; the second one is for the person(s) placing/moving/retrieving ground control points (GCPs), so they can operate in separate parts of the airport, completing needed tasks more quickly, while staying safe and aware of manned and unmanned aircraft operations.
- MTRI anemometer (for wind speed checking)
- MTRI iPad® Mini with GeoPDF airport map that includes recommended GCP locations to assist with placing GCPs (Avenza Maps® Application Installed)
- Clipboard(s)
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- High-visibility vests, hardhats, and protective eyewear
- Steel/composite toe boots/shoes

- Facemasks, hand sanitizer (see COVID-19 portion of MTRI safety plan)
- First aid kit(s) –at least one
- Emergency beacon lights (one for each vehicle present)
- Fire extinguisher (1)
- Bottled water, sunscreen
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed in the MTRI Geographic Information System (GIS) laboratory the day before field collection.

### C.3 FOCUS AREAS FOR DATA COLLECTION

For the May 14, 2021 data collection at ONZ, the following flights/data collections are planned:

- Mavic 2 Pro Enterprise Advanced (48 MP optical and 640x512 thermal):
  - Combined red, green, blue (RGB) and thermal data, 15.24-m flights (Runway 17/35 and Taxiway A).

In the previous December 2021 survey at ONZ, the focus was on Runway 17/35 and Taxiway A (TWAGI-10) because their condition was relatively worse than other airport areas, and these specific areas had feature types that were of higher priority to the FAA. Table C-1 provides detailed information of the available airfield pavement distresses on the different parts of ONZ. Data collected on May 2021 will be compared to data from the previous collection in December 2020 at ONZ with the Task 3 Report planned height and resolution. Figure C-1 shows the location of the planned Propeller AeroPoint GPS-enabled ground control points that will enable high-resolution positioning of photogrammetry outputs products, such as orthophotos and digital elevation models (DEMs).



Figure C-1. Locations of Runway 17/35 (Sections 10 and 20) and Taxiway A and the Locations of Planned AeroPoint GCP Targets

Table C-1. Pavement Distress Summary of ONZ (MDOT, 2018)

Facility	Section	Age (yr)	Surface Type	2018/2021 PCI	Distresses
Apron	10	51	PCC	46	ASR (L, M, H), corner break (M), corner spalling (L, M, H), faulting (L, M), joint seal damage (H), joint spalling (M, H), LTD cracking (L, M), shattered slab (M), small patching (H)
	20	13	PCC	64	Faulting (L), joint seal damage (H), large patching, LTD cracking (L, M), joint spalling (H), shrinkage cracking
Taxiway A	10	24	PCC	40	ASR (L, M), blow-up (L, M), corner break (L, M, H), faulting (L), joint seal damage (H), large patching (L, M, H), LTD cracking (L, M), shattered slab (L, M, H)
Taxiway C	10	13	PCC	90	ASR (L), corner spalling (L, M), joint seal damage (M, H), blow-ups (L), large patching (L), joint spalling (M)
	20	16	PCC	79	ASR (L, M), corner break (M), corner spalling (L, M, H), joint seal damage (M), joint spalling (M), LTD cracking (L, M), joint spalling (M)
T-hangar	10	34	PCC	43	ASR (H), corner break (L, H), corner spalling (L, M), faulting (L, M), joint seal damage (H), joint spalling (L, M, H), large patching (L), LTD cracking (L, M), shattered slab (M, H), shrinkage cracking
	20	21	PCC	17	ASR (L, M), corner break (H), corner spalling (H), joint seal damage (H), LTD cracking (L, M, H), shattered slab (M)
Runway 4/22	10	5	AC	99	L&T cracking (L)
Runway 17/35	10*	20	PCC	34	ASR (L, M), corner break (H), scaling (M), faulting (L, M), joint seal damage (H), LTD cracking (L, M)
Runway 17/35	20*	21	PCC	33	ASR (L, M), corner break (L, M), scaling (M), faulting (M), joint seal damage (M, H), LTD cracking (L, M), large patch (L, M, H), durability cracking (L, M, H), shattered slab (M)

L= Low severity, M=Medium severity, H=High severity

AC= Asphalt concrete pavement

PCC= Portland cement concrete pavement

PCI = Pavement Condition Index

ASR = Alkali-silica reaction

L&T cracking = Longitudinal and transverse cracking

LTD cracking = Longitudinal, transverse, and diagonal cracking

\*Data collected in 2021 as part of this study

## C.4 OBJECTIVES FOR DRONE DATA COLLECTION FRIDAY, MAY 12, 2021,

Flights made over Taxiway A may be shortened to cover only the western part due to aircraft traffic on Runway 4/22 that is approaching the taxiway. The reduced flights will occur between Runway 17/35 and Taxiway C if that is needed.

### C.4.1 Mavic 2 Enterprise Advanced

Mavic 2 Enterprise Advanced (M2EA) combined optical and thermal imagery will be collected over Runway 17/35 and Taxiway A. Several flights (battery changes) will be needed to cover these areas. Two M2EA units will be available, one with seven batteries, and one with six batteries. Batteries can be recharged during the day with an available generator. Note that times below are based on the Mavic 2 Pro, which is supported by the Pix4D capture application normally used to estimate flight times. Flight times for the M2EA should be similar. Average flight time is estimated at 20 minutes per battery.

#### **Runway 17/35**

- 15.24-m flights.
- Image resolution: Optical RGB = 3.4 mm; Thermal infrared (IR) = 20 mm
- Time to complete:
- Main runway: Approx. 130 minutes (seven flights)
- Southeast edge of runway that approaches Taxiway C (TWC) (sample units 128-131: 16 minutes (one flight))
- Total time: Approx. 146 minutes or 2 hours, 26 minutes (eight flights)

#### **Taxiway A**

- 15.24-m flights
- Image resolution: Optical RGB = 3.4 mm; Thermal IR = 20 mm
- Time to complete:
- Main taxiway area: Approx. 59 minutes (three flights)
- Extension near western end (sample units 8-19): 11 minutes (one flight)
- Extension towards apron A01GI-20 (sample units 30-37): 13 minutes (one flight)
- Extension at eastern end (sample units 86-96): 11 minutes (one flight)
- Total time: 94 minutes or 1 hour, 34 minutes (six flights)

Total time for all of Runway 17/35 and Taxiway A: 240 minutes or 4 hours (14 flights)

The flight plans for these missions have been estimated with the Pix4D Capture Android application. They will be flown with the new DJI Pilot application using the M2EA Smart Controller, which supports this newer drone. An 80% forward overlap and a 70% side overlap are being used, now standard for airport missions to ensure high-quality data.

Figure C-2 shows an example of the flight plan and the required time to complete M2EA data collection over the main part of Runway 17/35. Figure C-3 shows this for the southeast “extension”

that covers sample units 128-131. Because this area is out of line with the main straight stretch of the runway, this is mostly efficiently done as a separate data collection.

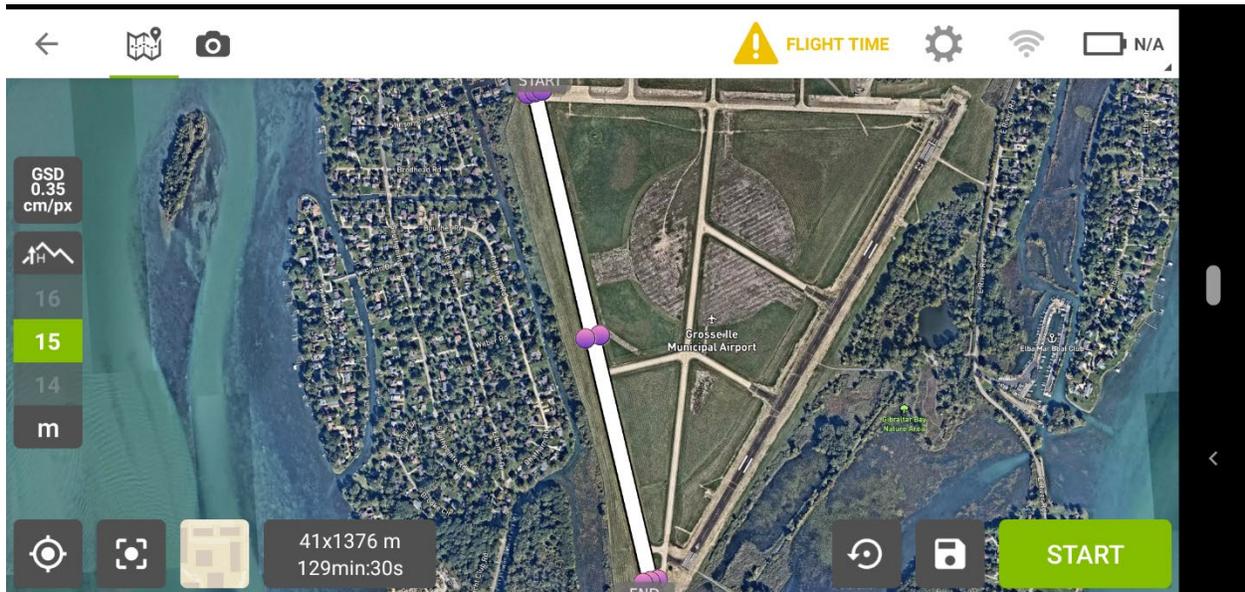


Figure C-2. Example Flight Plan and Estimated Completion Time (almost 130 minutes) for the Main Part of Runway 17/35

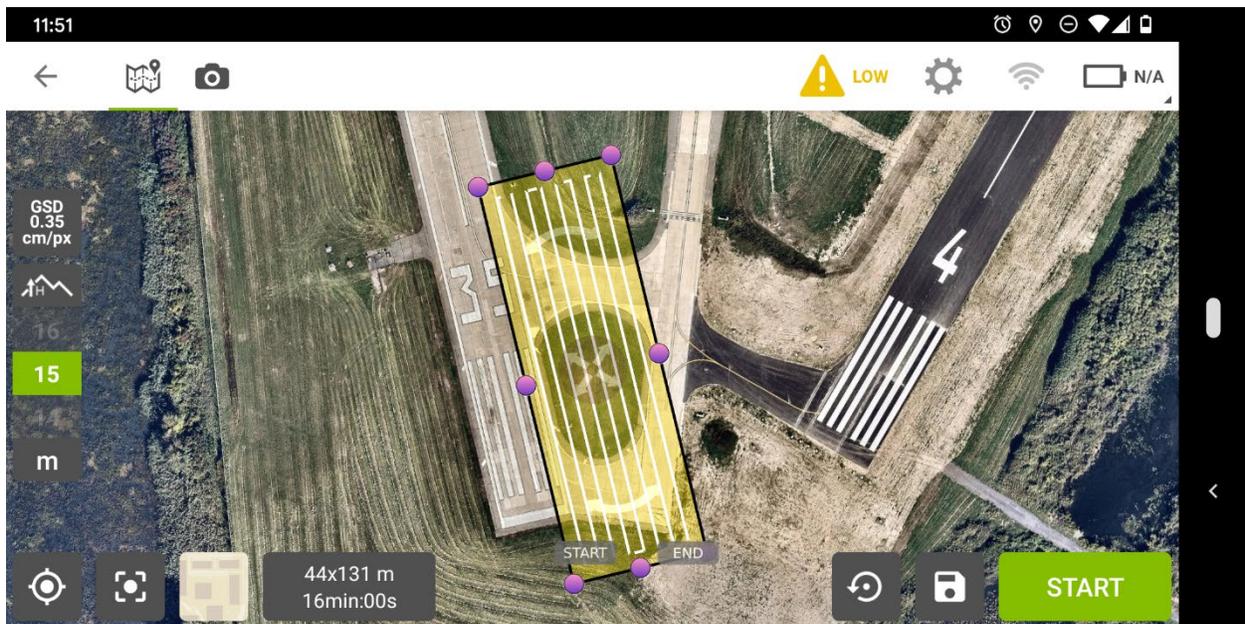


Figure C-3. Example Flight Plan and Estimated Completion Time (16 minutes) at the Southeast Extension of Runway 17/35

Figure C-4 shows an example flight plan for Taxiway A. Figure C-5 shows a flight plan for the western extension that covers sample units 8 to 19. Figure C-6 shows this for the extension towards the apron, covering sample units 30-37. Figure C-7 shows this for the eastern extension covering

sample units 86-96. These areas off the main straight part of Taxiway A are most efficiently collected through separate flights.

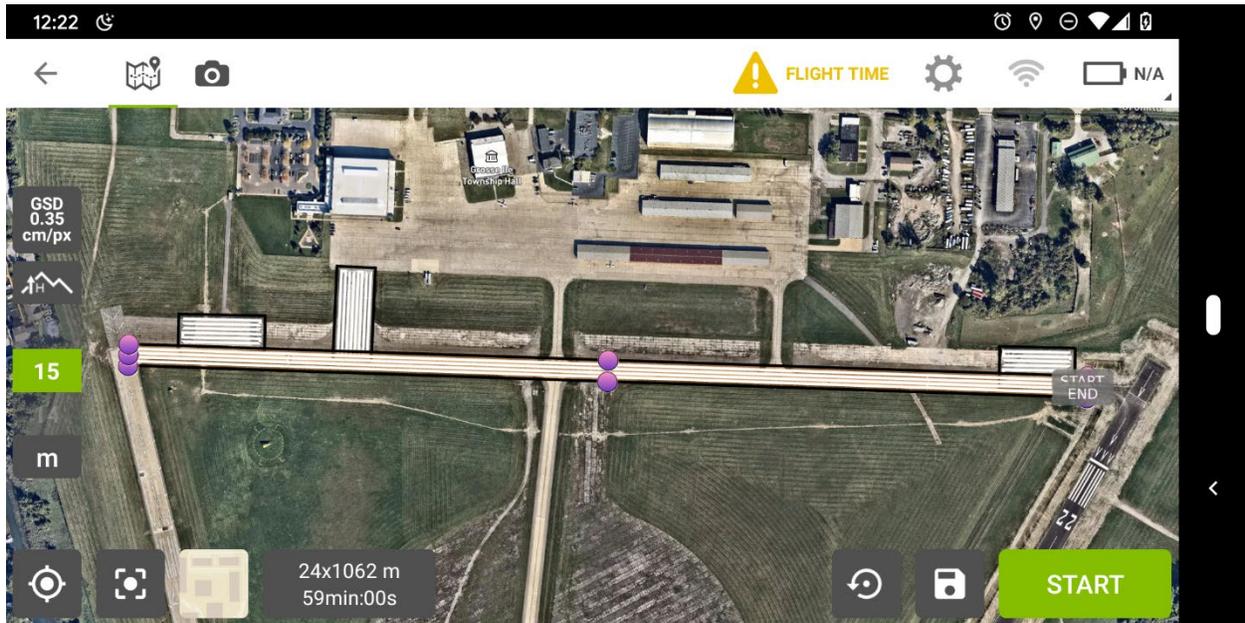


Figure C-4. Example Flight Plan and Estimated Completion Time (59 minutes) at the Main Part of Taxiway A

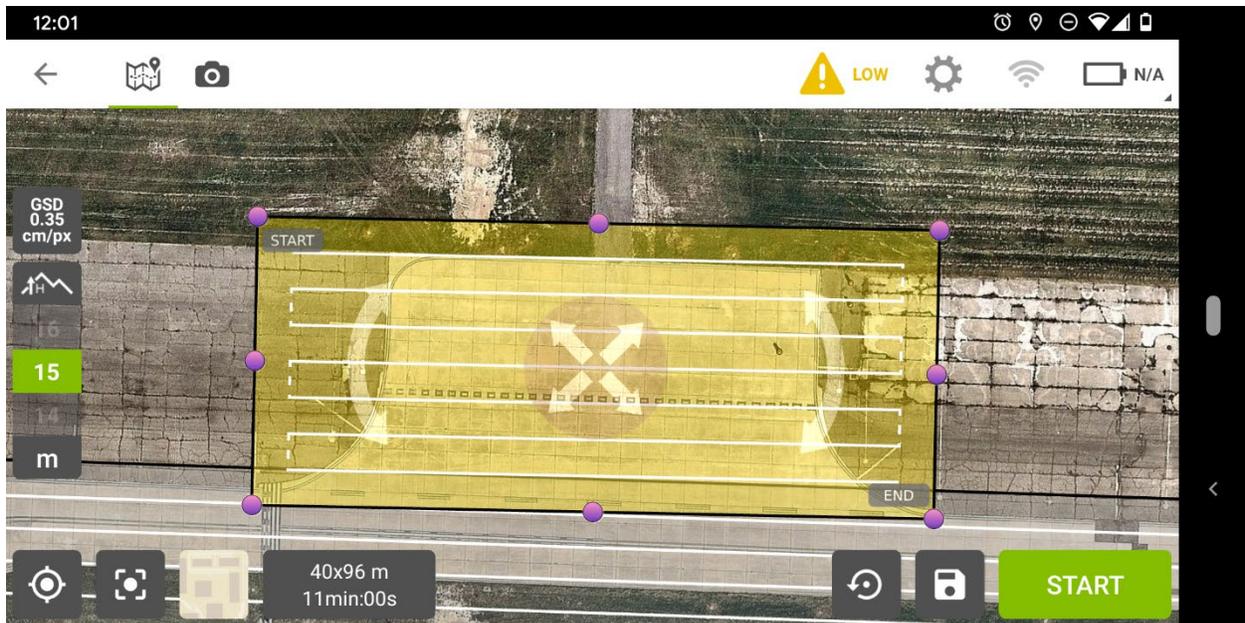


Figure C-5. Example Flight Plan and Estimated Completion Time (11 minutes) for the Western Extension for Sample Units 8 to 19

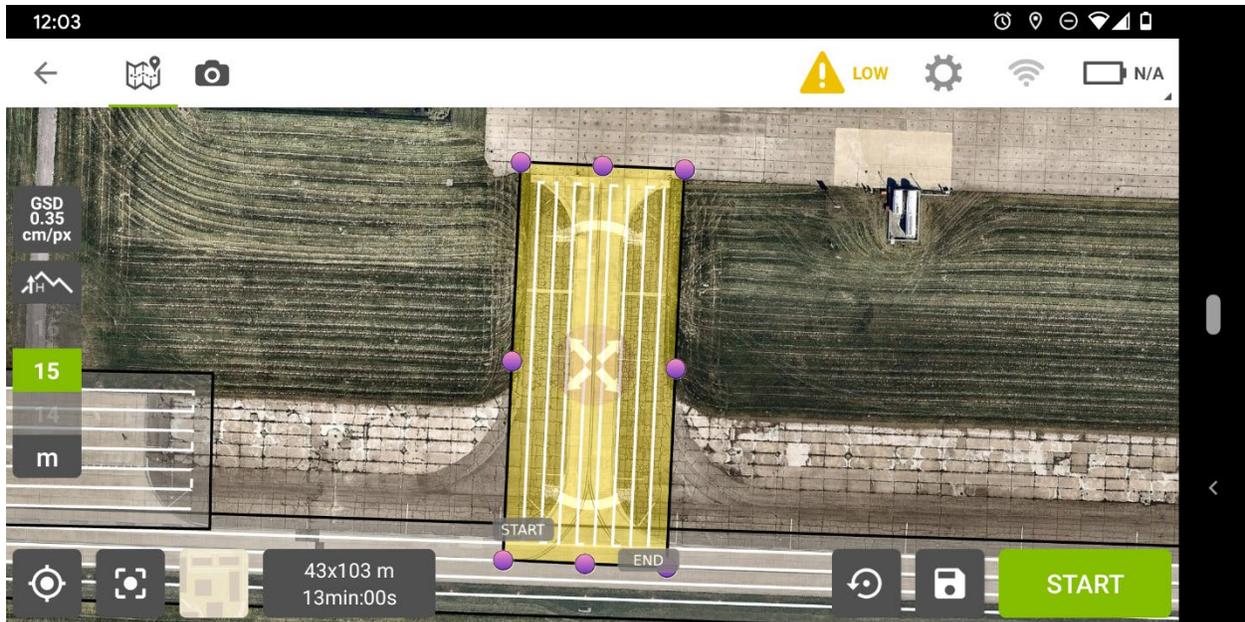


Figure C-6. Example Flight Plan and Estimated Completion Time (13 minutes) for the Extension Towards Apron A01GI-20 (sample units 30-37)

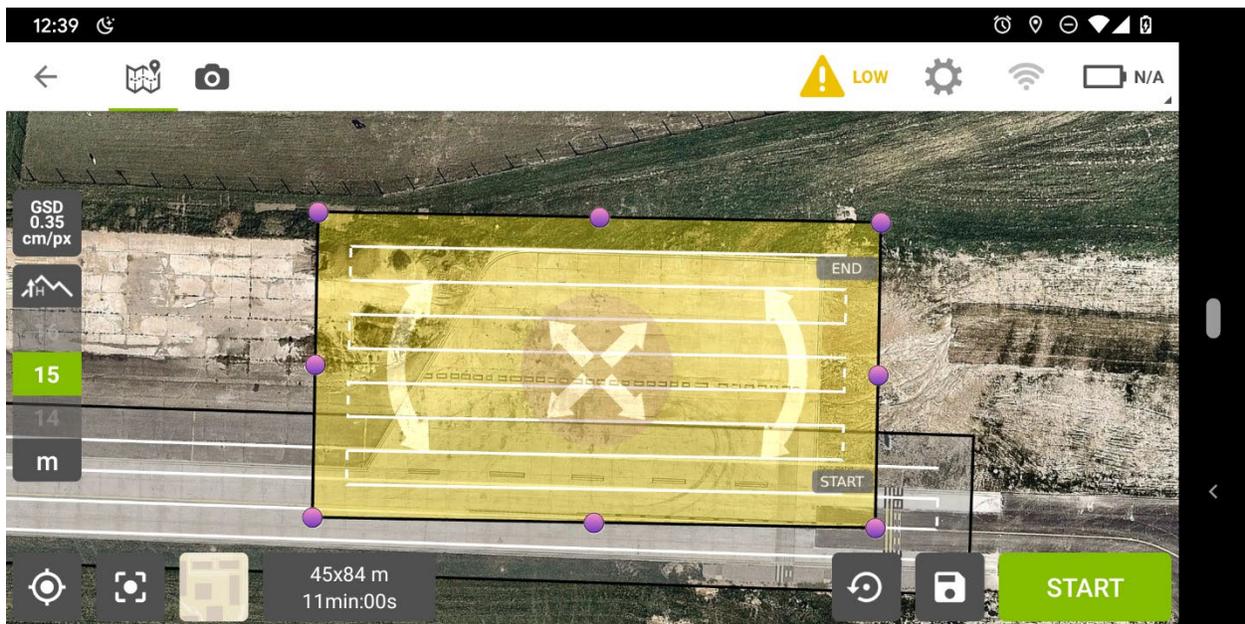


Figure C-7. Example Flight Plan and Estimated Completion Time (11 minutes) for the Extension at Eastern End of TWA (sample units 86-96)

### C.5 PILOTS AND SUPPORT TEAM

The MTRI team has three research staff available for this data collection (Colin Brooks, Chris Cook, and Ben Hart), all of whom have a current Part 107 Unmanned Pilot's Certificate. Abdullah Sourav from the Iowa State team will participate as well; he also has a Part 107 Unmanned Pilot's

Certificate. The standard procedure is to have at least two staff members for UAS flights, one UAS pilot and one safety observer. The third person usually focuses on deploying GCPs and documenting the data collection with ground field photos.

The provisional timeline for Friday, May 14, 2021 is provided below—timing is subject to change based on weather, equipment status, air traffic, airport operational needs, and similar factors.

There is brief downtime built into the timeline to accommodate battery/sensor swaps and to remain grounded while aircraft operate in the vicinity. The data-collection team will have their aviation radios on at all times on Unicom frequency 123.00 used for ONZ. Windows of moving vehicles will be kept open, with vehicle radios off, to enable listening for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 m from the runway centerline and 304.8 m from the ends of the runway will be used, and the team will stay outside these areas when not completing a data collection. The team will keep 76.2 m distance from side of any moving aircraft and will not operate UAS if wind gusts exceed 24.1 kmph or are predicted to be more than 24.1 mph 24 hours ahead of the data collection times. A hand-held anemometer will be used to measure wind speed before each mission.

The planned data collection timeline follows:

- 8:30—9:30: Set AeroPoint GCPs and prepare drones for operation
- 9:30—12:30: Collect Runway 17/35 data. Total estimated flight time needed: Approx. 146 minutes or 2 hours, 26 minutes (8 flights)
- 12:30—13:30: Break for lunch/catch-up time for Runway 17/35 if needed
- 13:30—15:30: Collect Taxiway A data. Total estimated flight time needed: 94 minutes or 1 hour, 34 minutes (6 flights)
- 15:30 – 16:00: Recover GCPs and leave ONZ

All missions will be documented by a photographer designated for each mission, from one of the Michigan Tech staff who is not flying the UAS or acting as an observer.

Figure C-8 is the ApTech Network Definition Map for ONZ (north is at the left). Figures C-9, C-10, and C-11 are drone RGB photos from the December 11, 2020 data collection at ONZ that show the Runway 17/35 and Taxiway A locations.





Figure C-10. Northern Part of Runway 17/35 at Left and Most of Taxiway A Along the Middle of the Photograph, as Collected by Michigan Tech Mavic Drone on December 11, 2020



Figure C-11. The Remainder of Taxiway A, Part of Taxiway C at Center Going to the Lower Right, and Part of Runway 4/22 at the Middle Right

## C.6 REFERENCES

MDOT. (2018). *Grosse Ile Municipal Airport Pavement Management Report*.

APPENDIX D—AIRPORT CONDITION SURVEY SAFETY PLAN FOR GROSSE ILE MUNICIPAL AIRPORT, GROSSE ILE TOWNSHIP, MICHIGAN IN MAY 2021

This safety plan was developed for small unmanned aircraft system (sUAS) safe data collection from Grosse Ile Municipal Airport (ONZ) in Grosse Ile Township, Michigan. This document was developed along with the data collection plan provided in Appendix C. Figures D-1 and -D2 show the travel plans for the research team. Figure D-3 highlights the ONZ layout and location of the ground control points (GCPs).

Data collection: May 14, 2021

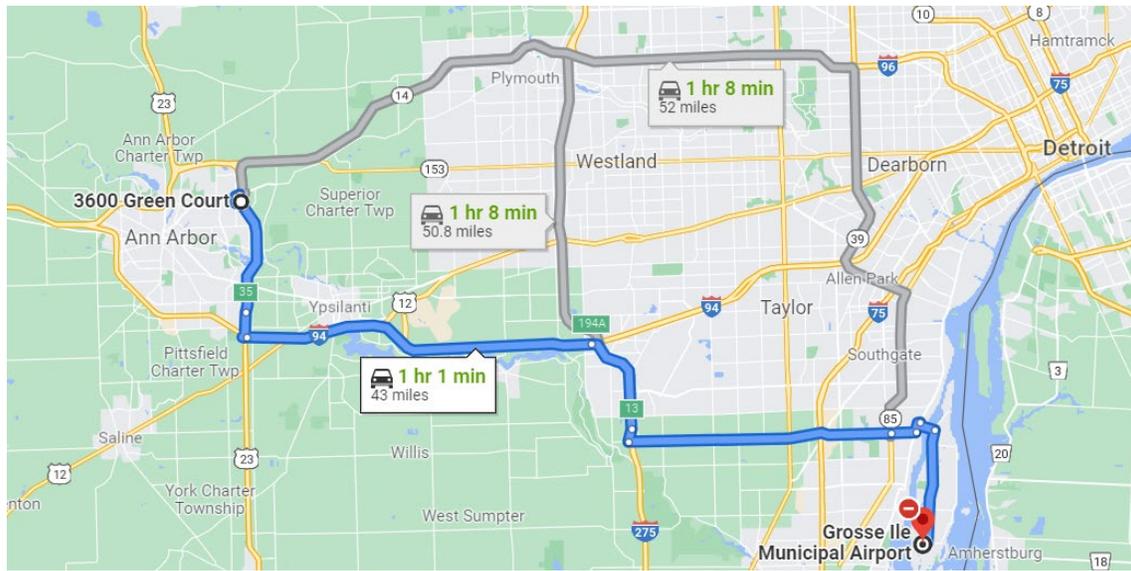


Figure D-1. Travel Route from Ann Arbor, Michigan to the Grosse Ile, Michigan Site Location

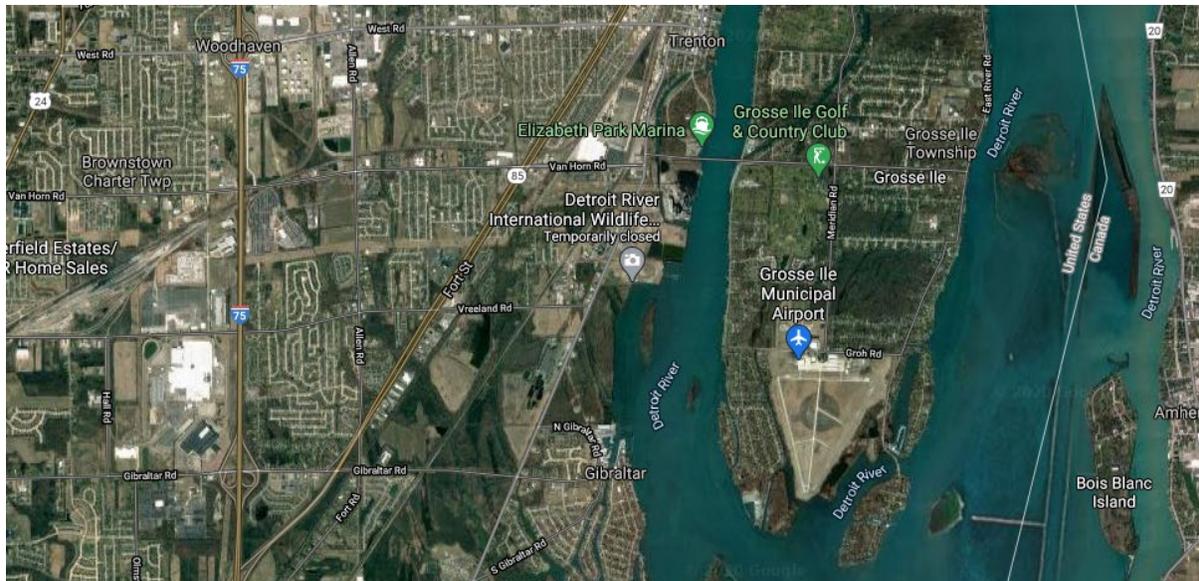


Figure D-2. Location of ONZ



Figure D-3. Location of the Ground Control Points

## D.1 CONTACT INFORMATION

For any safety questions during field data collection, please contact:

- Richard Dobson (Lead pilot-in-command)

Other participants are:

- Chris Cook (road & drone safety observer, backup pilot)
- Julie Carter (ground control data collector, backup road and drone safety observer)

Proposed schedule

Will depart Michigan Tech Research Institute (MTRI) at 7:50 a.m., arriving at ONZ at approximately 8:30 a.m. (travel time to ONZ from MTRI is approximately 40 minutes). Survey the airport area, pack up, and head back to the office by 3:30 p.m. local time.

## D.2 FIELD SITE

ONZ near Grosse Ile Township, Michigan. The ONZ airport manager is Michael Duker, who has agreed to the latest UAS field deployment. He will issue a Notice to Airmen (NOTAM) for airport operations, now planned for May 14, 2021.

## D.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have a hard hat and reflective vest. Driving vehicles must have yellow caution lights present.

- A stand-up safety briefing will be held at the beginning of any data-collection days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (hardhat, steel- or composite-toe boots, high-visibility vest, glasses) at all times.
- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic, and the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- The team will be operating on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching a landing along the runway or taxiway being surveyed by sUAS, the team will cease operations (land sUAS) and continue after the manned aircraft have finished their takeoff or landing procedures.
- The data collection team will have two components: an sUAS data collection team and a GCP data collection team that will each have their own Sporty's<sup>®</sup> 400 aviation radio, which will be on at all times while performing data collection operations (including setup and takedown time) on Unicom frequency 123 used for ONZ.
- Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways.

- Team will remain conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member takes measurements of any kind in an area with traffic or other safety risks, another crew member must spot them.
- Standing on runways or taxiways is permitted only during data collections if needed.
- Standing in open traffic lanes present at the airport is not permitted. If walking along an open stretch of roadway, crew members should walk against the flow.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside the Runway Safety Area. The team is using a representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends (305 m), so the team will stay outside these areas when not completing a data collection. They will keep away 76.2 m horizontally from any moving aircraft.

#### D.4 sUAS SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants one day prior to field collections of where the sUAS will be operating, safe places, and minimum distance to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a remote pilot's certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly. Additional safety guidelines include:

- Remain a safe distance from and do not stand directly below a flying drone.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are operated unless it is an immediate emergency.
- All drone operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until the safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of the sUAS operation in case of a battery fire.

#### D.5 FIRST AID AND MEDICAL

- The first aid kit will be on site with the field crew for all site visits.
- The emergency telephone number is 911.
- Nearest hospital location to study site: Beaumont Hospital, Trenton (17.9 km, 23 minutes), 5450 Fort St, Trenton, Michigan 4818 Phone: (734)-671-3800 (non-emergency).
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead). Any workplace injury must be reported to Lisa and appropriate forms filled out if medical care is sought due to any workplace injuries.

## D.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- The field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew will travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
- Field equipment will be individually assigned as much as possible (e.g., whoever starts with a particular drone will use that one the rest of the day) and will be disinfected with Lysol<sup>®</sup>-type wipes when possible.
- Multiple crew members are permitted to travel within the same vehicle when the University's Health and Safety Level is at Level 3. Level 3 requires a face covering for everyone when riding in a vehicle with more than one person. The vehicle must be sanitized between uses. Crew members who regularly travel/work together may sit up to two people per seat row; all others follow Level 4 guidance, which requires sitting in separate rows.
- As of 03/18/2021, the University is at Level 3. (<https://www.mtu.edu/flex/operations/levels/>)
- Note that there is a cleaning protocol for the MTRI Durango that MUST be followed—laminated copies can be found inside the Durango.
- All field work must comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
- COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
- Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
- Research Pandemic Checklist: Research Pandemic Checklist - Google Docs
- When the University is at Level 3, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX E—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN FOR CUSTER AIRPORT, MONROE, MICHIGAN IN MARCH 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Custer Airport (TTF) in Monroe, Michigan. This document was developed along with the safety plan provided in Appendix F.

Data collection dates: March 12 and 22, 2021 (weather permitting)

### E.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with integrated 20-mp camera (both) with spare batteries [charged]
- Controller [charged]
- Integrated Controller [charged]
- Spare 4G Pixel™ phone as a backup controller [charged]
- Bergen Hexacopter with spare batteries [charged]
- Controller [charged]
- First-person view (FPV) screen [charged]
- Forward-looking infrared (FLIR) Thermal camera (FLIR Vue Pro R 640 x 512 30 hz) [batteries charged]
- Optical camera (Nikon D850 45.7 mp) [batteries charged]
- Tetracam micro-MCA6 multispectral imaging system [battery charged]
- mdMapper-1000+ with spare batteries [charged].
- Controller [charged]
- Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]

### E.2 OTHER EQUIPMENT

- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- Folding takeoff pad
- Generator and gas can
- Trimble® Geographic Information System (GPS) unit with decimeter accuracy (Michigan Tech Research Institute [MTRI]) [charged]
- Ground control targets (32 available from MTRI)
- Ground control targets nails (to keep GCPs in place in soil areas).
- Rugged Olympus Tough TG-5® GPS Camera (12 mp) - (for geolocated field photos) (1) [charged]
- Sony Alpha® Camera (16 mp) for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least two copies), filled out in advance
- Sporty's® SP-400 aviation radios (2), tuned to TTF Unicom frequency 122.7 for the entire time the team is onsite at TTF
- One aviation radio is for the two-person sUAS flight team. The second one is for the person(s) placing GCPs and recording their location with high-resolution Global Positioning System (GPS) to operate in separate parts of the airport. In this way, necessary

tasks can be completed more quickly while adhering to safety precautions and remaining aware of manned and unmanned aircraft operations on or near TTF.

- MTRI anemometer (for wind-speed checking)
- MTRI iPad® Mini with GeoPDF airport map that includes recommended ground control point (GCP) locations to assist with placing GCPs
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- High-visibility vests, hardhats, and protective eyewear
- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of MTRI safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled water
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed in the MTRI Geographic Information System (GIS) laboratory the day prior to field collection.

### E.3 AIRPORT CONTACT INFORMATION

TTF Airport manager: Dan Diesing (734-384-9616 office). MTRI researcher Richard Dobson met with Mr. Diesing on October 29, 2020, and he welcomed sUAS data collection at his airport. Dr. Brooks called him on February 12, 2021, and Mr. Diesing continued to welcome data collection at his airport.

Airport webpage:

<https://www.monroemi.gov/cms/one.aspx?portalId=10126595&pageId=10353502> SkyVector webpage about TTF: <https://skyvector.com/airport/TTF/Custer-Airport>

### E.4 FOCUS AREAS FOR DATA COLLECTION

The focus of the data collection will be on Runway 3/21 (RW321MN-10) and Taxiway A (TWAMN-10 and TWAMN-30) at Custer Airport (TTF, near Monroe, Michigan), which has a grooved, single asphalt overlay over asphalt concrete pavement (AAC) runway (see Figure E-1). Most of the taxiway (section 10) is airport asphalt concrete (AC), while the smaller part (Section 30) is AAC. In 2017, the runway had an area-weighted overall pavement condition index (PCI) rating of 82, and Taxiway A had an area-weighted PCI rating of 63. In January 2021, a manual distress survey conducted by APTEch, the runway PCI had fallen to 74, whereas Taxiway A Section 10 had a PCI of 63.



Figure E-1. Site Photographs from the October 29, 2020 Visit: (a) Part of Runway 3/21 Showing Grooved AAC Surface and (b) Part of TWAMN-10 with AC Surface

Based on APTech’s Pavement Management Report published in 2018, longitudinal and transverse (L&T) cracking, swelling, and weathering is expected along the runway (see Table E-1 below). TWAMN-10 has depressions, L&T cracking, raveling, and weathering. TWAMN-30 has L&T cracking, patching, and weathering. The total runway area is 47963 square m, the area of TWAMN-10 is 214,843 square ft (19,959 square m), and the area of TWAMN-30 is 1118.2 square m. The runway and taxiway are 1,524 m long.

For Runway 3/21 and Taxiway A, the priority is to collect representative higher-resolution data at a subset of the sampling units to continue building relevant datasets to demonstrate the feasibility of drone-enabled airport pavement inspection that can meet the requirements of ASTM standard D5340. A more detailed follow-up sUAS survey will be conducted later, preferably in Q2 2021.

With the January 18–20, 2021 ApTech manual surveys of TTF and ONZ completed, location-specific GIS distress data are now available and have helped to focus on three sample units (SU): SU 53 for Runway 3/21, and SU 23 and SU 25 for TWA-10. The manual distress results for these three sample units are included in Tables E-2 and E-3. RW321 SU53 has all three types of distresses found on the runway (Type 48 = L&T Cracking, 56 = Swell, 57 = Weathering). TWA-10 SU23 has three types of distresses found at Taxiway A (48, 52 = Raveling, 57), and TWA-10 SU25 has those three plus the only recorded location of distress type 45 (Depression). They are also relatively close to each other (within 106.7 m, see Figure E-2), so all three distresses can be collected with one 18.29-m or 9.14-m above ground level (AGL) flight with the Bergen Hexacopter, increasing efficiency and the likelihood of getting all areas surveyed in a single day at TTF.

Table E-1. Pavement Distress Summary of TTF (MDOT, 2019)

Facility	Section	Age (yr)	Surface Type	2018/2021 PCI	No. of Distresses	Distresses
Apron	*10	33	PCC	66	8	Corner break (L, H), corner spalling (L, M, H), durability cracking (L, M), faulting (L, M), joint spalling (L, M), large patching (L), LTD cracking (L, M), small patching (L), joint seal damage (L)
	20	36	AAC	11	3	Alligator cracking (M), block cracking (M), raveling (M, H)
	30	4	AC	100	0	None
Taxiway A	*10	19	AC	63	4	Depression, L&T cracking (L, M), raveling (L), weathering (M)
	30	11	AAC	73	4	L&T cracking (L, M), raveling (L, M, H), weathering (L), patching (L)
T-hangar	10	19	AC	62	6	Depression (L), L&T cracking (L, M), raveling (H), rutting (L), swelling (M), weathering (M, H)
	20	4	AC	100	0	None
	30	11	AAC	76	3	L&T cracking (L), patching (M), weathering (L)
Runway 3/21	*10	10	AAC	74	3	L&T cracking (L, M), swelling (L), weathering (L)

L= Low severity, M=Medium severity, H=High severity  
 AC= Asphalt concrete pavement  
 PCC= Portland cement concrete pavement  
 ASR = Alkali-silica reaction  
 L&T cracking = Longitudinal and transverse cracking  
 LTD cracking = Longitudinal, transverse, and diagonal cracking  
 \*Data collected in 2021 as part of this study

Table E-2. Manual Survey Distress Data for RW321 SU 53

Sample unit	Sample PCI	Distress	Severity	Paver quantity	Units
53	70	L&T cracking	L	53.0	m
			M	41.5	m
		Swell	L	0.7	m <sup>2</sup>
		Weathering	L	464.5	m <sup>2</sup>

L= Low severity, M=Medium severity, H=High severity  
 L&T cracking = Longitudinal and transverse cracking

Table E-3. Manual Survey Distress Data for TWA-10 SU 23 and SU 25

Sample unit	Sample PCI	Distress	Severity	PAVER Quantity	Units
23	65	L&T cracking	L	49.4	m
			M	38.1	m
		Raveling	L	8.8	m <sup>2</sup>
		Weathering	M	406.5	m <sup>2</sup>
25	54	Depression	L	1	m <sup>2</sup>
		L&T cracking	L	17.1	m
			M	40.5	m
		Raveling	L	23.4	m <sup>2</sup>
Weathering	M	406.5	m <sup>2</sup>		

L= Low severity, M=Medium severity, H=High severity  
 L&T cracking = Longitudinal and transverse cracking



Figure E-2. Location of Recommended High-Resolution Sample Units

Two flights will capture all of Runway 3/21, and two will capture all of Taxiway A (TWAMN-10 and TWAMN-30 together), with each of these areas having flights occurring at different heights

to help evaluate how different resulting resolutions may help identify particular distresses while still allowing for rapid data collection. Flight details will be recorded on standard MTRI flight logging forms. More information on planned heights is included below. Data collection focus areas and locations of the GCPs are provided in Figure E-3.

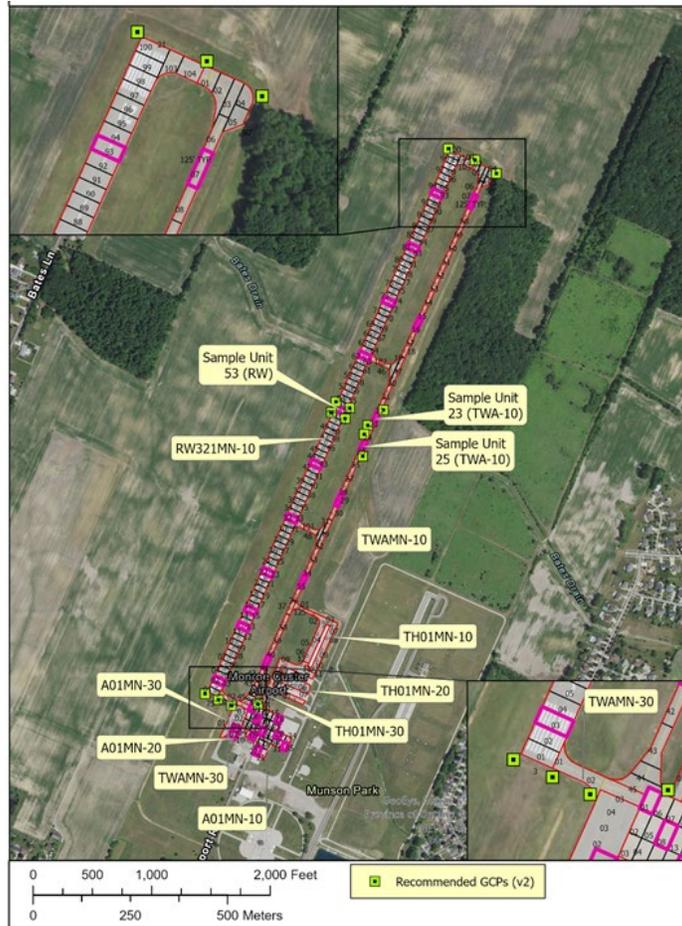


Figure E-3. Overview of TTF and Sampling Focus Areas, Including Recommended Locations for 15 Ground Control Points

## E.5 OBJECTIVES FOR UPCOMING MARCH 2021 sUAS DATA COLLECTION

### E.5.1 Mavic 2 Pro

Mavic 2 Pro 20 megapixel (mp) optical imagery will be collected over Runway 3/21 and both parts of Taxiway A (Sections 10 and 30 together). A 91.44-m height mission was tried at ONZ Grosse Ile, but it did not meet most distress detection needs. A 30.48-m height mission appeared to be more useful based on reviews of results so far. A 24.38-m height mission is planned to assess its usefulness with additional distress detection and evaluation. Lower heights would require more than two flights per mission for the Mavic 2 platform, which is not recommended at this point. If necessary, the 24.4 m mission will be prioritized because example 30.5 m data at ONZ was previously collected.

A total of at least four preplanned missions is likely to be needed to cover both separate altitudes. Below are the planned flights with the team's Mavic 2 sUAS:

### Runway 3/21

- The 24.38-m AGL flight will collect 6-mm/pix (0.23 inch/pix) resolution imagery and require an estimated 21 minutes to complete (one planned mission, with one or two flights needed).
- The 30.48-m AGL flight will collect 7-mm/pix (0.3 inch/pix) resolution imagery and require an estimated 18 minutes to complete (one planned flight).

### Taxiway A (Sections 10 and 30 together)

- The 24.38-m AGL flight will collect 6-mm/pix (0.23 inch/pix) resolution imagery and require an estimated 38 minutes to complete (one planned mission, most likely requiring two flights).
- The 30.48-m AGL flight will collect 7-mm/pix (0.3 inch/pix) resolution imagery and require an estimated 26 minutes to complete (one planned mission, most likely requiring two flights).

The flight plans for these missions are created with the Pix4D Capture Android application, the same used for ONZ mission planning and previous research. The team is using an 80% forward overlap and a 70% side overlap, standard for most missions where they will be using close-range photogrammetry software to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully for creating outputs for the 30.48-m and 91.44-m flights at ONZ and were most often in past sUAS photogrammetry missions. Figure E-4 shows a draft of a preplanned mission for the runway at 24.4 m based on using the Mavic 2 Pro sUAS.

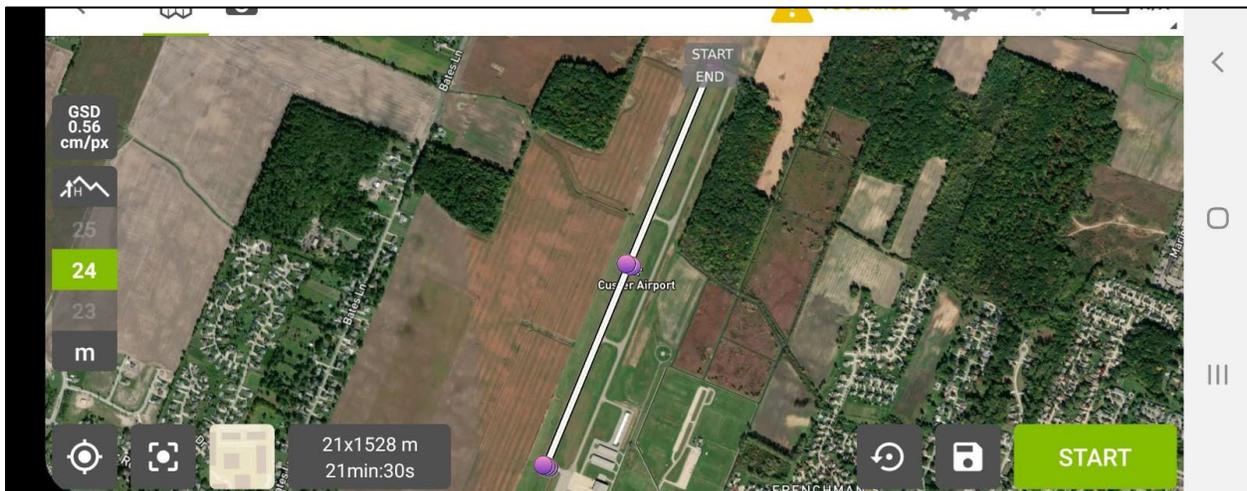


Figure E-4. Example 24.4-m Pix4Dcapture Mission Cover RW321MN-10 Showing A 21.5-Minute Mission Time

### E.5.2 Bergen Hexacopter

The Bergen Hexacopter will be flown manually to collect at least optical imagery from two altitudes: 9.1 m and 18.3 m over the previously selected three total sample units of Runway 3/21 and Taxiway A for detailed surveys, details are provided in Table E-4. These sample units are 15.2 m x 30.5 m (464.7 m<sup>2</sup>) for most of the runway and 10.7 m x 38.1 m, 407.7 m<sup>2</sup> for most of Taxiway A. The Bergen Hexacopter flight plan is listed below in Table E-4.

Table E-4. Planned Sensors and Flying Heights for Bergen Deployments

Sensor	9.14-m Height	18.28-m Height
Nikon D850 45.7-mp optical	Yes	Yes
FLIR Vue Pro R 640x512 thermal	If time allows	Yes
Tetracam 6-band multispectral	If time allows	Yes

Note: Each sensor requires a separate flight.

To complete the missions in one data collection day, the team has already collected sample 9.14-m optical and thermal data at ONZ and is focusing on 18.3 m as the target height to assess if this is a reasonable compromise between data-collection time and needed resolutions.

Because of the closeness of the three selected sample units, it is anticipated that these will be covered in one flight per sensor type. If all three sensors are completed at both heights, that will be a total of six Bergen flights, which may be challenging to accomplish in a single day. If the D850 optical and Tetracam at only an 18.28-m height are done, that will be more reasonable for Bergen flights.

Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired sample units are. At 9.1 m, the optical will have a 1-mm resolution, whereas the thermal imagery will be 8 mm. At 18.3 m, the optical imagery will have 1.9-mm resolution, the thermal imagery will be 16 mm, and the Tetracam will have 10-mm resolution. The 9.14-m height was previously selected for ONZ as a representative height useful for higher resolution 3D data creation, based on experience. There were some issues obtaining sufficient overlap with the manually controlled Bergen system at 9.1 m height, and thermal imagery was difficult to merge when collected at this height because of a lack of readily identifiable automatic tie points. Therefore, it is recommended that the focus be on the 18.28-m height for TTF. Manual control will be used because the planned data collection areas are small, and the older Bergen flight control hardware and software are not compatible with current mission planning applications.

### E.5.3 mdMapper-1000+

The team also has a German-made mdMapper-1000+ sUAS that is focused on photogrammetric optical data collection, purchased in 2020 to detect map defects on bridge decks and measure 3D rates of construction progress. A test of this system is proposed for at least one sample unit, for at least an 18.28-m data collection, to demonstrate how its automated flight-planning capabilities are likely to be more suitable for low-height data collections than the older Bergen system. The

mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 18.3 m, the optical imagery will have a 2.3-mm resolution.

## E.6 PILOTS AND SUPPORT TEAM

The Michigan Tech team has four research staff available for this project, all of whom have a current Part 107 Unmanned Pilot's Certificate. There is also a geospatial research intern who can help with ground control point GPS data collection. Standard procedure is to have at least two staff members for sUAS flights: one sUAS pilot and one safety observer. A third crew member with the supporting intern will collect the 15 GCPs that are thought to be sufficient to cover this site.

*Provisional timeline for data collection day – All timing is subject to change based on weather conditions and airport operations.*

A 1-hour data collection per sample unit data collection area is likely to be sufficient to capture thermal, optical, and multispectral data per planned height. As noted, RW321 SU53 and TWA-10 SU 23 and SU25 will be collected as one area. If both 9.14-m and 18.28-m data are collected for each sample unit, a second hour is likely to be needed for both data-collection areas. Downtime will be used to accommodate battery/sensor swaps and remain grounded while aircraft operate in the vicinity.

The data-collection team will have their aviation radio on at all times for data collections on Unicom frequency 122.7, used for TTF. Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside the Runway Safety Area. A representative Runway Safety Area will be used of 76.2 meters from the runway centerline and 304.8 m from the runway ends. The team will stay outside these areas when not completing a data collection. The team will keep away 76.2 m horizontally from any moving aircraft. The team will not operate sUAS if wind gusts exceed 24 kmph or are predicted to be more than 24 kmph 24 hours ahead of the data collection times. A hand-held anemometer will be used to measure wind speed before each mission. Snow on the pavement areas and temperatures below 32 °F during data- collection times will also prevent data collection.

The planned data-collection timeline is as follows:

- 9:00 – 10:00: Set ground control point targets for Runway 3/21 and Taxiway A.
- 10:00 – 12:00: Collect optical, thermal, and multispectral data with Bergen Hexacopter at 18.3 m (priority) and 9.1 m height (if possible) for the central airport sample unit focus area, covering RW321 SU53 and TWA-10 SU23 and SU25. Start collecting decimeter-resolution GCP locations with the Trimble unit.
- 12:00 – 13:00: Collect 24.38-m and 30.48-m Mavic 2 data for Runway 3/21. GCP data collector ensures the team gets lunch.
- 13:00 – 15:00 Collect 24.38-m and 30.48-m Mavic 2 data for Taxiway A. GCP data collector completes GPS data collection.

- 15:00 – 16:00: Demonstrate 18.29-m mdMapper-1000+ data with Sony 42.4-mp camera for at least one sample unit (three if time allows).
- 16:00 – 16:30: Remove GCPs and exit the airport.

All missions will be documented by a photographer designated for each mission, from one of the Michigan Tech staff, not flying the sUAS or acting as an observer (this is usually one of the GCP data-collection crew members).

A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date in case any final modifications are needed. Field photo of TTF collected by APTech during PCI data collection are provided in Figures E-5 through E-8. In addition, PCI inspection map and survey results are also illustrated in Figures E-9 to E-12.



Figure E-5. Longitudinal and Transverse Cracking at RW 321 10 SU 53



Figure E-6. Depression at TWA 10 SU 25



Figure E-7. Raveling at TWA 10 SU 7



Figure E-8. Weathering at RW321 10 SU 63

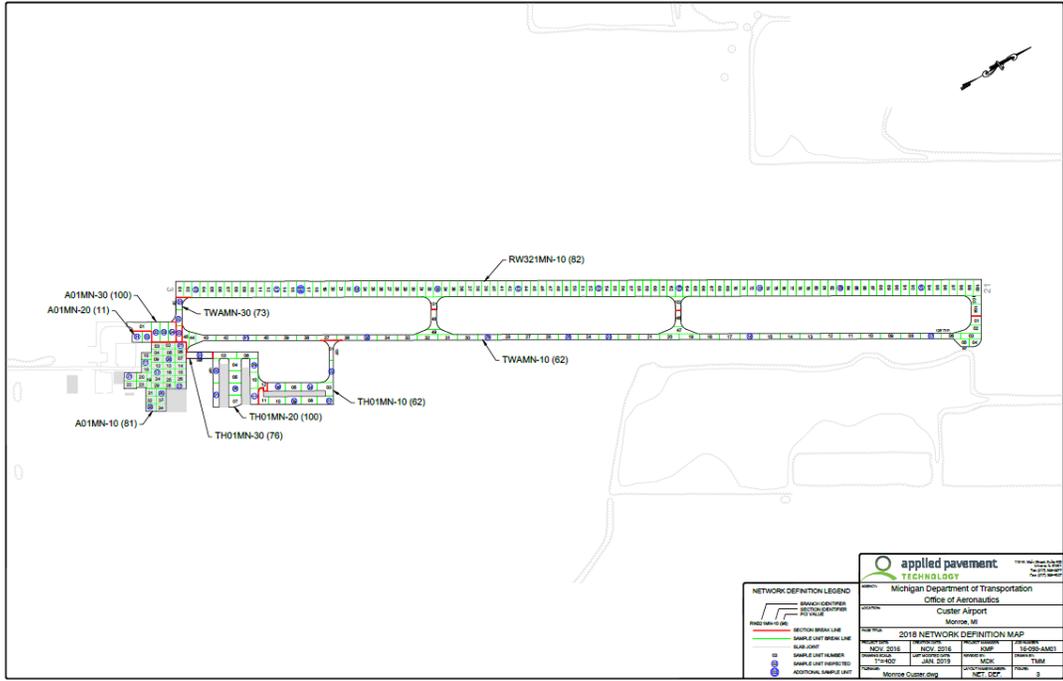


Figure E-9. APTech's Inspection Map of TTF (MDOT, 2019)

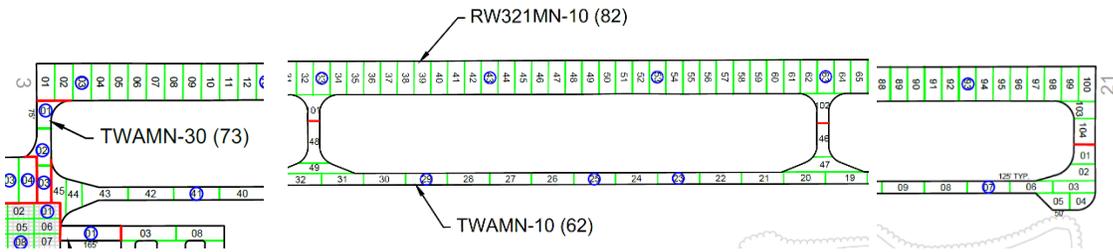


Figure E-10. APTech's Runway 3/21 and Taxiway A Inspection Map of TTF (MDOT, 2019)

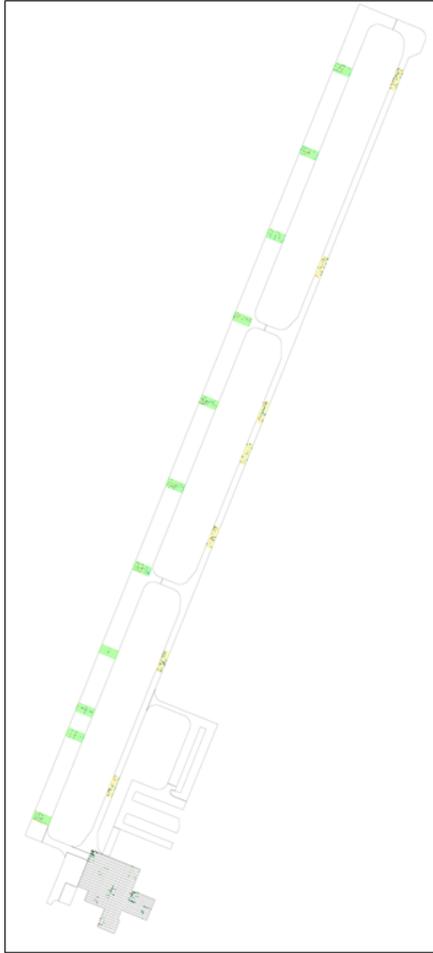


Figure E-11. Location of the Sample Units of Manual Pavement Inspection Conducted in January 2021



Figure E-12. Location and Pavement Distresses on the High-Resolution Data sUAS Collection Sample Units at TTF

## E.7 REFERENCES

MDOT. (2019). *Custer Airport Pavement Management Report*.

## APPENDIX F—AIRPORT CONDITION SURVEY SAFETY PLAN FOR CUSTER AIRPORT, MONROE, MICHIGAN IN MARCH 2021

This safety plan was developed for safe data collection from Custer Airport (TTF). This document was developed along with the data collection plan provided in Appendix E. Figures F-1 and F-2 show the travel plans and airport location, respectively. Figure F-3 highlights TTF layout and location of the GCPs.

Data collection: March 12 and 22, 2021

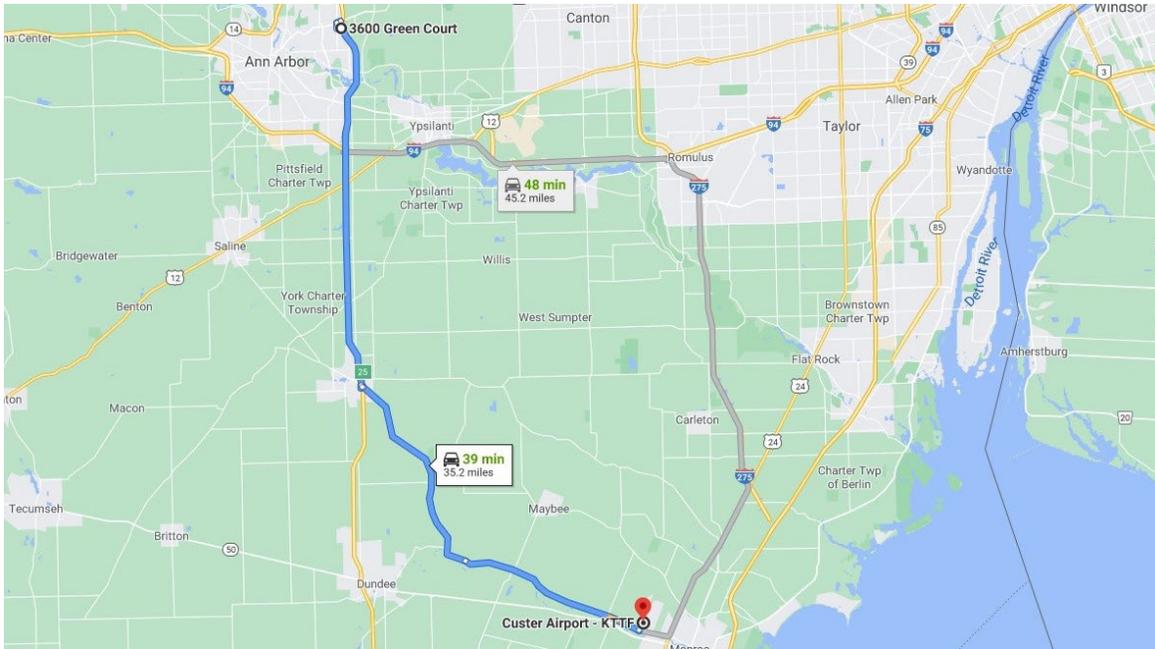


Figure F-1. Travel Route from Ann Arbor, Michigan to Custer Airport

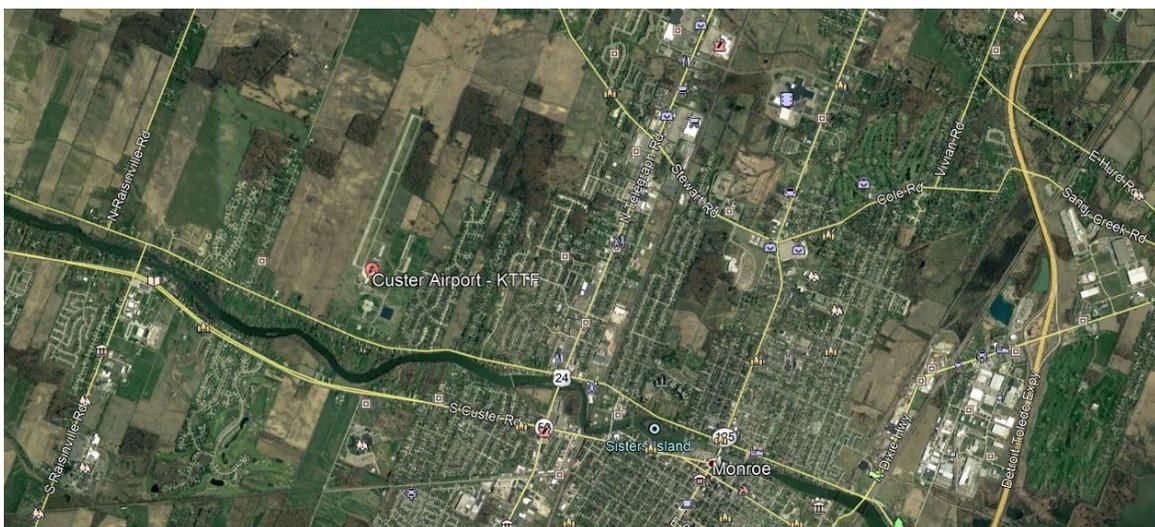


Figure F-2. Location of Custer Airport

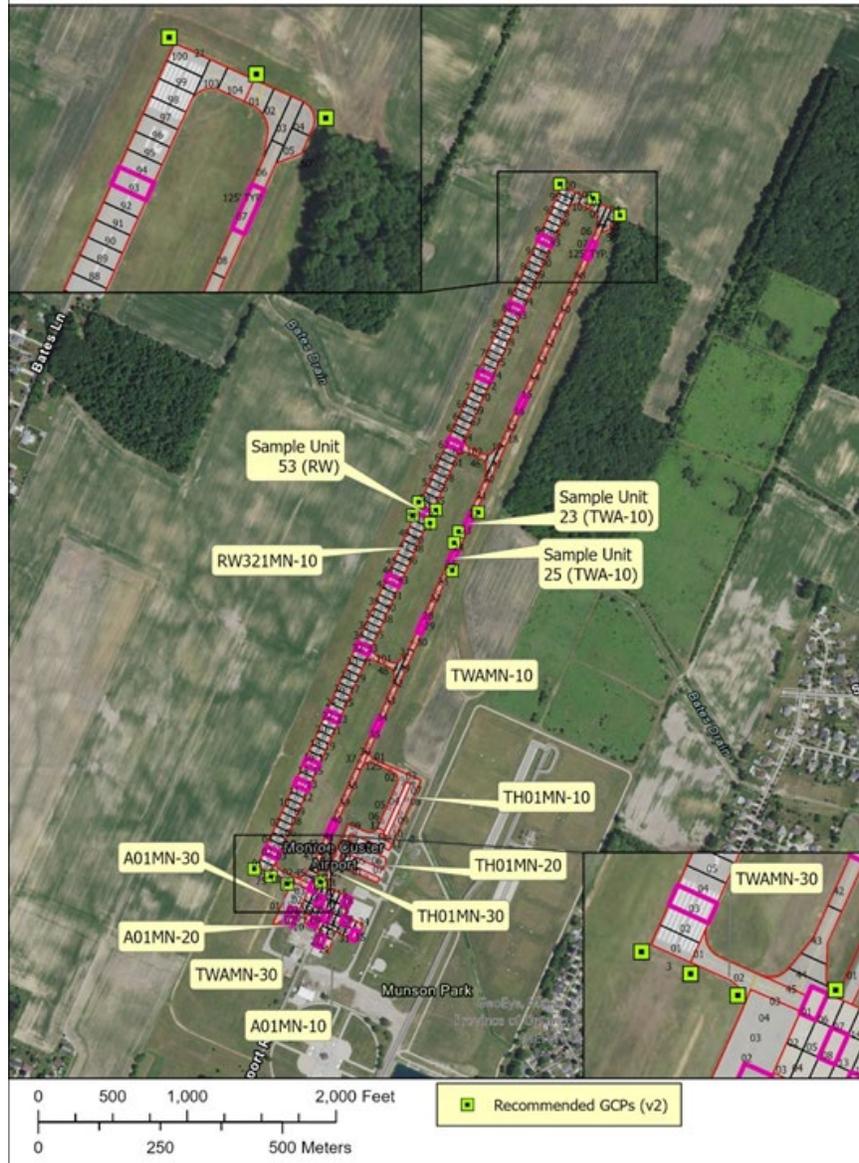


Figure F-3. Location of the Ground Control Points

## F.1 CONTACT INFORMATION

For any safety questions during field data collection, please contact:

- Richard Dobson (Lead Pilot-in-command)

Other participants are:

- Chris Cook (road & drone safety observer, backup pilot)
- Julie Carter (ground control data collector, backup road and drone safety observer)

Proposed schedule:

Will depart Michigan Tech Research Institute (MTRI) at 7:50 a.m., arriving at Grosse Ile Airport at approximately 8:30 a.m. (travel time to Grosse Ile from MTRI is approximately 40 minutes). Survey the airport area, pack up, and head back to the office by 3:30 p.m. local time.

## F.2 FIELD SITE

Deployment will occur at TTF near Monroe, Michigan. The TTF airport manager is Dan Diesing, who has agreed to sUAS field deployment. Dan will issue a Notice to Airmen (NOTAM) as he did for the March 12, 2022 data collection to inform pilots that drone operations will occur at this General Aviation airport.

## F.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have hard hats and reflective vests. Driving vehicles must have yellow caution lights present. Additionally, the following safety guidelines will be observed.

- A stand-up safety briefing will be held at the beginning of any data-collection days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (hardhat, steel- or composite-toe boots, high-visibility vest, glasses) at all times.
- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic and the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- Operation will be on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching a landing along the runway or taxiway being surveyed by sUAS, the team will cease operations (land sUAS) and continue them after the manned aircraft have finished their takeoff or landing procedures.
- The data-collection team will have two components: an sUAS data collection team and a GCP data collection team that will each have their own Sporty's® 400 aviation radio, which will be on at all times while performing data collection operations (including setup and takedown time) on Unicom frequency 122.7, used for TTF.
- Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways.
- Crew members should always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member takes measurements of any kind in an area with traffic or other safety risks, another crew member must spot them.
- Crew members should avoid standing on runways or taxiways during data collections unless necessary.
- Crew members should not stand in open traffic lanes present at the airport. If walking along an open stretch of roadway, crew member should walk against the flow of traffic.

- As noted in the data-collection plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends is being used, so the team will stay outside these areas when not completing a data collection. The team will keep away 76.2 m horizontally from any moving aircraft.

#### F.4 sUAS SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants 1 day prior to field collections of where the sUAS will be operating, safe places, and minimum distance to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a Remote Pilots Certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots may fly.

- Remain a safe distance from and do not stand directly below a flying drone.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are operated unless it is an immediate emergency.
- All drone operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until the safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of the sUAS operation in case of a battery fire.

#### F.5 FIRST AID AND MEDICAL

- The first aid kit will be on site with the field crew for all site visits.
- The emergency number is 911.
- Nearest hospital location to study site: ProMedica Monroe Regional Hospital, Monroe (4.8 km, 8 minutes). 718 N Macomb St, Monroe, Michigan 48162; Phone: (734) 240-8400 (non-emergency).
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead). Any workplace injury must be reported to Lisa, and appropriate forms filled out if medical care is sought due to any workplace injuries.

#### F.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- The field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew must travel with hand sanitizer and use it at the beginning and end of the day, and all breaks.
- Field equipment will be individually assigned as much as possible (for example, whoever starts with a particular drone will use that one throughout the rest of the day) and will be disinfected with sanitizing wipes when possible.

- Multiple workers are allowed to travel within the same vehicle when the University's Health and Safety Level is at Level 3. Level 3 requires a face covering for everyone when riding in a vehicle with more than one person. The vehicle must be sanitized between uses. Employees and students who regularly travel/work together may sit up to two people per seat row; all others follow Level 4 guidance, which requires sitting in separate rows.
- As of 03/18/2021, the University is at Level 3. (<https://www.mtu.edu/flex/operations/levels/>)
- Crew members MUST FOLLOW the established cleaning protocol for the MTRI Durango—laminated copies can be found inside the Durango.
- Fieldwork must comply with the Michigan Tech COVID-19 fieldwork protocol and safety checklist found at the following locations:
  - COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
  - Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
  - Research Pandemic Checklist: Research Pandemic Checklist - Google Docs
- Now that the University is back at Level 3, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/ Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX G—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN FOR CUSTER AIRPORT, MONROE, MICHIGAN IN MAY 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from targeted areas of Custer Airport (TTF) in Monroe, Michigan. This document was developed along with the safety plan provided in Appendix H.

Data Collection Date: May 21, 2021 (weather permitting)

### G.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with integrated 20-mp camera (both) with spare batteries [charged]
- Controller [charged]
- Integrated controller [charged]
- Spare 4G Pixel™ phone as a backup controller [charged]
- Bergen Hexacopter with spare batteries [charged]
- Controller [charged]
- First-person view (FPV) screen [charged]
- Forward-looking infrared (FLIR) thermal camera (FLIR Vue Pro R 640 x 512 30 hz) [batteries charged]
- Optical camera (Nikon D850 45.7 mp) [batteries charged]
- Tetracam micro-MCA6 multispectral imaging system [battery charged]
- mdMapper-1000+ with spare batteries [charged]
- Controller [charged]
- Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]

### G.2 OTHER EQUIPMENT

- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- Folding takeoff pad
- Generator and gas can (Michigan Tech Research Institute [MTRI])
- Trimble® Geographic Information System (GPS) unit with decimeter accuracy (MTRI) [charged]
- Ground Control Points (GCPs) (32 available from MTRI)
- GCP nails (to keep GCPs in place in soil areas)
- Rugged Olympus Tough TG-5® GPS Camera (12 mp)—(for geolocated field photos) (1) [charged]
- Sony Alpha camera (16 mp) for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least 2 copies)
- Sporty's® SP-400 aviation radios (2), tuned to TTF Unicom frequency 122.7 for the entire time the team is onsite at TTF
- One aviation radio is provided for the two-person sUAS flight team. The second one is provided for the person(s) placing GCPs and recording their location with high-resolution Global Positioning System (GPS) to operate in separate parts of the airport. This makes it

easier to complete necessary tasks more quickly while maintaining safety and awareness of manned and unmanned aircraft operations on or near TTF.

- MTRI anemometer (for checking wind speed)
- MTRI iPad® Mini with GeoPDF airport map that includes recommended ground control point (GCP) locations to assist with placing GCPs
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- High-visibility vests, hardhats, and protective eyewear
- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of MTRI safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled water
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed in the MTRI Geographic Information System (GIS) laboratory the day prior to field collection.

### G.3 AIRPORT CONTACT INFORMATION

TTF Airport manager: Dan Diesing (734-384-9616, office number). MTRI researcher Richard Dobson met with Mr. Diesing on October 29, 2020, and he welcomed sUAS data collection at his airport. Dr. Brooks followed up with him with a telephone call on February 12, 2021, and Mr. Diesing continued to welcome data collection at his airport.

Airport webpage:

<https://www.monroemi.gov/cms/one.aspx?portalId=10126595&pageId=10353502>

SkyVector webpage about TTF: <https://skyvector.com/airport/TTF/Custer-Airport>

### G.4 FOCUS AREAS FOR DATA COLLECTION

Data collection will focus on Runway 3/21 (RW321MN-10) and Taxiway A (TWAMN-10 and TWAMN-30) at TTF, near Monroe, Michigan, which has a grooved, single asphalt overlay over asphalt concrete pavement (AAC) runway (see Figure G-1). Most of the taxiway (Section 10) is asphalt cement concrete (AC), while the smaller part (Section 30) is AAC. In 2017, the runway had an area-weighted overall PCI rating of 82, and Taxiway A had an area-weighted PCI rating of 63. In a January 2021, in a manual distress survey conducted by APTEch, the runway PCI had fallen to 74, whereas Taxiway A Section 10 had a PCI of 63.



Figure G-1. Site Photographs from October 29, 2020 Showing (a) Part of Runway 3/21 with Grooved AAC Surface and (b) Part of TWAMN-10 with AC Surface

Based on ApTech’s Pavement Management Report published in 2018, it was expected that there would be longitudinal and transverse (L&T) cracking, swelling, and weathering along the runway (see Table G-1 below). TWAMN-10 has depressions, L&T cracking, raveling, and weathering. TWAMN-30 has L&T cracking, patching, and weathering. The total runway area is 47963 square m, the area of TWAMN-10 is 19959.6 square m, and the area of TWAMN-30 is 1118.2 square m. The runway and taxiway are 1524 m long.

For Runway 3/21 and Taxiway A, the priority is to collect representative higher-resolution data at a subset of the sampling units to continue building relevant datasets to demonstrate the feasibility of drone-enabled airport pavement inspection that can meet requirements of ASTM standard D5340. A more detailed follow-up sUAS survey will be conducted later, preferably in Q2 2021.

With the January 18–20, 2021 APTEch manual surveys of TTF and ONZ completed, location-specific GIS distress data are now available and have helped us focus on three sample units (SUs): SU 53 for Runway 3/21, and SU 23 and SU 25 for TWA-10. The manual distress results for these three SUs are included in Tables G-2 and G-3. RW321 SU53 has all three types of distresses found on the runway (Type 48 = L&T Cracking, 56 = Swell, 57 = Weathering). TWA-10 SU23 has three types of distresses found at Taxiway A (48, 52 = Raveling, 57), and TWA-10 SU25 has those three, and is the only recorded location of distress type 45 (Depression). They are also relatively close to each other (within 106.7 m, see Figure G-2), so all three distresses can be collected with one 18.29-m or 9.14-m above ground level (AGL) flight with the Bergen Hexacopter, increasing efficiency and the likelihood of getting all areas surveyed in a single day at TTF.

Table G-1. Pavement Distress Summary of TTF (MDOT, 2019)

Facility	Section	Age (yr)	Surface type	2018/2021 PCI	Distresses
Apron	*10	33	PCC	66	Corner break (L, H), corner spalling (L, M, H), durability cracking (L, M), faulting (L, M), joint spalling (L, M), large patching (L), LTD cracking (L, M), small patching (L), joint seal damage (L)
	20	36	AAC	11	Alligator cracking (M), block cracking (M), raveling (M, H)
	30	4	AC	100	None
Taxiway A	*10	19	AC	63	Depression, L&T cracking (L, M), raveling (L), weathering (M)
	30	11	AAC	73	L&T cracking (L, M), raveling (L, M, H), weathering (L), patching (L)
T-hangar	10	19	AC	62	Depression (L), L&T cracking (L, M), raveling (H), rutting (L), swelling (M), weathering (M, H)
	20	4	AC	100	None
	30	11	AAC	76	L&T cracking (L), patching (M), weathering (L)
Runway 3/21	*10	10	AAC	74	L&T cracking (L, M), swelling (L), weathering (L)

L= Low severity, M=Medium severity, H=High severity

AC= Asphalt concrete pavement

PCC= Portland cement concrete pavement

PCI = Pavement Condition Index

ASR = Alkali-silica reaction

L&T cracking = Longitudinal and transverse cracking

LTD cracking = Longitudinal, transverse, and diagonal cracking

\*Data collected in 2021 as part of this study

Table G-2. Manual Survey Distress Data for RW321 SU 53

Sample Unit	Sample PCI	Distress	Severity	Paver Quantity	Units
53	70	L&T cracking	L	53.0	m
			M	41.5	m
		Swell	L	0.7	m <sup>2</sup>
		Weathering	L	464.5	m <sup>2</sup>

L= Low severity, M=Medium severity, H=High severity  
 L&T cracking = Longitudinal and transverse cracking

Table G-3. Manual Survey Distress Data for TWA-10 SU 23 and SU 25

Sample Unit	Sample PCI	Distress	Severity	PAVER Quantity	Units
23	65	L&T cracking	L	49.4	m
			M	38.1	m
		Raveling	L	8.8	m <sup>2</sup>
		Weathering	M	406.5	m <sup>2</sup>
25	54	Depression	L	1	m <sup>2</sup>
		L&T cracking	L	17.1	m
			M	40.5	m
		Raveling	L	23.4	m <sup>2</sup>
Weathering	M	406.5	m <sup>2</sup>		

L= Low severity, M=Medium severity, H=High severity  
 L&T cracking = Longitudinal and transverse cracking



Figure G-2. Location of Recommended High-Resolution Sample Units

The plan is for two flights to capture all of Runway 3/21 and for two flights to capture all of Taxiway A (TWAMN-10 and TWAMN-30 together). Flights occurring at different heights for each of these areas will help to evaluate how the different resulting resolutions can identify particular distresses while allowing for rapid data collection. Locations of the GCPs and the location of the high-resolution sample units are highlighted in Figure G-3. Flight details will be recorded on standard MTRI flight logging forms. More information on planned heights follows.

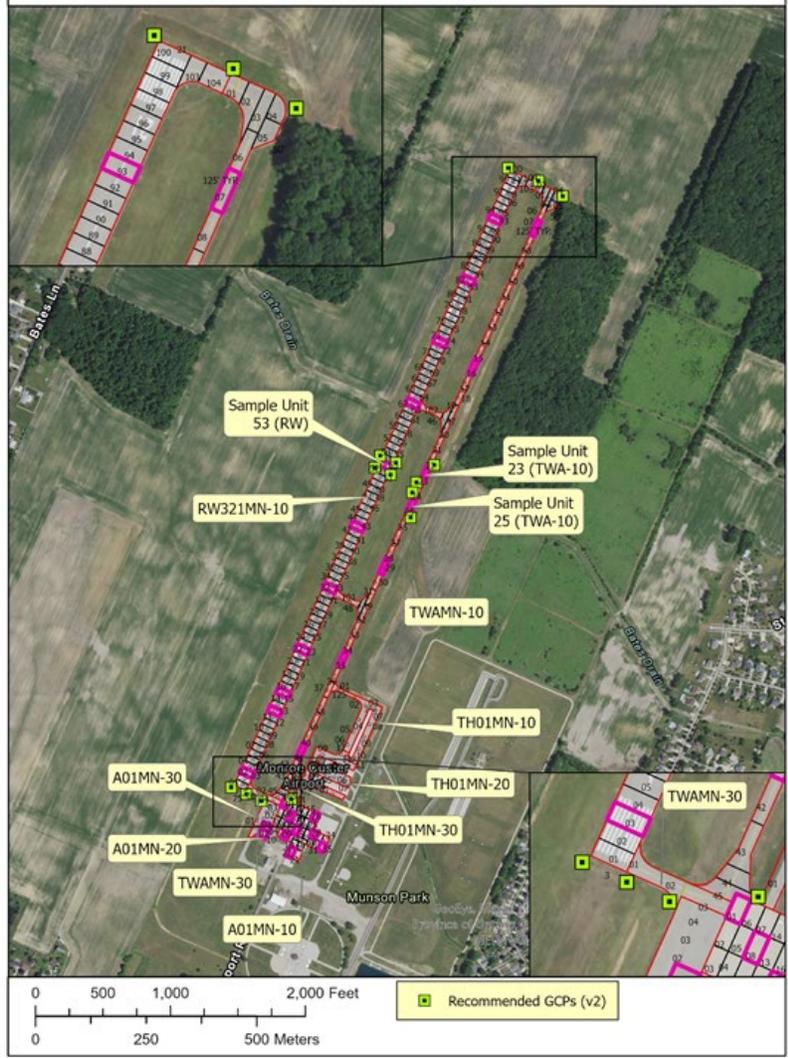


Figure G-3. Overview of TTF and Sampling Focus Areas, Including Recommended Locations for 15 Ground Control Points

G.5 OBJECTIVES FOR UPCOMING MARCH 2021 sUAS DATA COLLECTION

G.5.1 Mavic 2 Pro

Mavic 2 Pro 20 megapixel (mp) optical imagery will be collected over Runway 3/21 and both parts of Taxiway A (Sections 10 and 30 together). A 91.44-m height mission was tried at Grosse Ile Municipal Airport (ONZ) in Grosse Ile, Michigan but did not meet most distress detection needs. A 30.48-m height mission was more useful based on the reviews of the most recent results. A 24.38-m height mission is planned to assess whether it can help with additional distress detection and evaluation; lower heights would require more than two flights per mission for the Mavic 2 platform, which is not being recommended at this point. If necessary, the 24.38-m mission will be prioritized because sample 30.48-m data at ONZ was previously collected.

A total of at least four preplanned missions are likely to be needed to cover both separate altitudes. Following are the planned flights with the team's Mavic 2 sUAS:

### **Runway 3/21**

- The 24.38-m AGL flight will collect 6-mm/pix (0.23 inch/pix) resolution imagery and require an estimated 21 minutes to complete (one planned mission, with one or two flights needed).
- The 30.48-m AGL flight will collect 7-mm/pix (0.3 inch/pix) resolution imagery and require an estimated 18 minutes to complete (one planned flight).

### **Taxiway A (Sections 10 and 30 together)**

- The 24.38-m AGL flight will collect 6-mm/pix (0.23 inch/pix) resolution imagery and require an estimated 38 minutes to complete (one planned mission, most likely requiring two flights).
- The 30.48-m AGL flight will collect 7-mm/pix (0.3 inch/pix) resolution imagery and require an estimated 26 minutes to complete (one planned mission, most likely requiring two flights).

The flight plans for these missions are created with the Pix4D Capture Android application, used for ONZ mission planning and previous research. The team is using an 80% forward overlap and a 70% side overlap, standard for most of the missions where close-range photogrammetry software will be used to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully for creating outputs for the 30.5-m and 91.4-m flights at ONZ and have been used most often in past sUAS photogrammetry missions. Figure G-4 shows a draft of a preplanned mission for the runway at 24.4 m based on use of the Mavic 2 Pro sUAS.

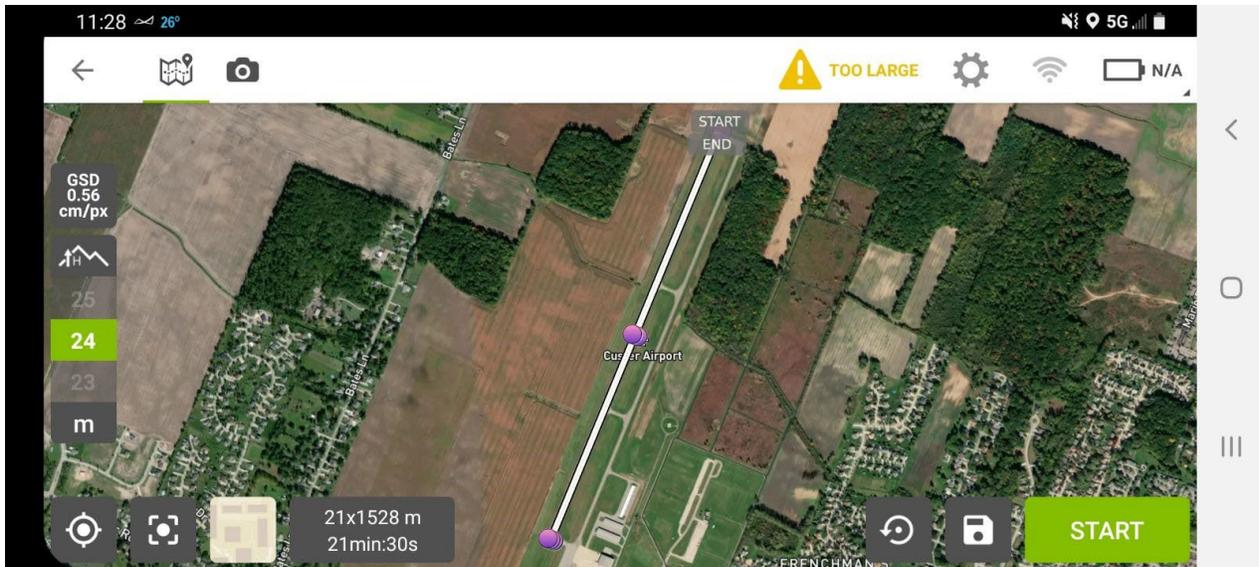


Figure G-4. Example 24.4-m Pix4Dcapture Mission Cover RW321MN-10 Showing a 21.5-Minute Mission Time

### G.5.2 Bergen Hexacopter

The Bergen Hexacopter will be flown manually to collect optical imagery at a minimum from two altitudes (9.1 m and 18.4 m) over previously selected three total sample units of Runway 3/21 and Taxiway A for detailed surveys. These sample units are 15.2 m x 30.5 m (464.5 m<sup>2</sup>) for most of the runway and 10.7 m x 38.1 m (406.5 m<sup>2</sup>) for most of Taxiway A. The flying plan for Bergen is shown in Table G-4.

Table G-4. Planned Sensors and Flying Heights for Bergen Deployments

Sensor	9.14-m Height	18.29-m Height
Nikon D850 45.7 mp optical	Yes	Yes
FLIR Vue Pro R 640x512 thermal	If time allows	Yes
Tetracam 6-band multispectral	If time allows	Yes

Note: each sensor requires a separate flight.

To get these missions completed in one data-collection day, after already collecting sample 9.14-m optical and thermal data at ONZ, the team is focusing on 18.3 m as the height to see if this can be a reasonable compromise between data-collection time and needed resolutions.

Because of the closeness of the three selected sample units, it is anticipated that these will be covered in one flight per sensor type. If all three sensors are done at both heights, that will be six Bergen flights total, which may be challenging to accomplish in a single day. Therefore, it would be more reasonable for Bergen flights if the D850 optical and Tetracam are done at only 18.29-m height.

Each flight will require 3 to 10 minutes to complete, depending on the distance between the paired sample units. At the 9.14-m height, the optical will have a 1-mm resolution, whereas the thermal imagery will be 8 mm. At the 18.3-m height, the optical imagery will have 1.9-mm resolution, the thermal imagery will be 16 mm, and the Tetracam will be 10 mm resolution. The 9.14-m height was previously selected for ONZ as a representative height useful for higher resolution 3D data creation, based on experience. There were some issues obtaining sufficient overlap with the manually controlled Bergen system at 9.14-m height, and thermal imagery was difficult to merge when collected at this height because of a lack of readily identifiable automatic tie points. Therefore, focusing on the 18.29-m height for TTF is recommended. Manual control is planned because of the small areas planned for data collection, and the older Bergen flight control hardware and software are not compatible with current mission planning applications.

### G.5.3 mdMapper-1000+

The team also has a German-made mdMapper-1000+ sUAS that is focused on photogrammetric optical data collection. The mdMapper-1000+ was purchased in 2020 for detecting map defects on bridge decks and measuring 3D rates of construction progress. Testing is proposed for this system for at least one sample unit, for at least an 18.29-m data collection, to demonstrate how its automated flight planning capabilities are likely to be more suitable for low-height data collections than the older Bergen system. The mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 60 feet, the optical imagery will have a 2.3-mm (0.09 inch) resolution.

## G.6 PILOTS AND SUPPORT TEAM

The MTRI team has four research staff available for this project, all of whom have a current Part 107 Unmanned Pilot's Certificate. There is also a geospatial research intern who can help with ground control point GPS data collection. The standard procedure is to have at least two staff members for sUAS flights, one being the sUAS pilot and the other being a safety observer. A third crew member with the supporting intern will collect the 15 GCPs that are believed to be sufficient to cover this site.

*Provisional timeline for data collection day – All timing is subject to change based on weather conditions and airport operations.*

A 1-hour data collection per sample unit data-collection area is likely to be sufficient to capture thermal, optical, and multispectral data per planned height. As noted, RW321 SU53 and TWA-10 SU 23 and SU25 will be collected as one area. If both 9.1 m and 18.3 m data are collected for each sample unit, a second hour is likely to be needed for both data-collection areas. Downtime will be used to accommodate battery/sensor swaps and remain grounded while aircraft operate in the vicinity.

The data-collection team will have their aviation radio on at all times for data collections on Unicom frequency 122.7 used for TTF. Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside the Runway Safety

Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends is being used, so the team will stay outside these areas when not completing a data collection. The team will keep away 76.2 m horizontally from any moving aircraft and will not operate sUAS if wind gusts exceed 24 kmph or are predicted to be more than 24 kmph 24 hours ahead of the data-collection times. A hand-held anemometer will be used to measure wind speed before each mission. Snow on the pavement areas and temperatures below 0 °C during data-collection times will also prevent data collection.

Below is the planned data-collection timeline:

- 9:00 – 10:00: Set GCP targets for Runway 3/21 and Taxiway A.
- 10:00 – 12:00: Collect optical, thermal, and multispectral data with Bergen Hexacopter at 18.29-m (priority) and 9.14-m heights (if possible) for the central airport sample unit focus area, covering RW321 SU53, and TWA-10 SU23 and US25. Start collecting decimeter-resolution GCP locations with the Trimble unit.
- 12:00 – 13:00: Collect 24.38-m and 30.48-m Mavic 2 data for Runway 3/21. GCP data collector ensures the team gets lunch.
- 13:00 – 15:00: Collect 24.38-m and 30.48-m Mavic 2 data for Taxiway A. GCP data collector complete GPS data collection.
- 15:00 – 16:00: Demonstrate 18.29-m mdMapper-1000+ data with Sony 42.4-mp camera for at least one sample unit (3 if time allows).
- 16:00 – 16:30: Remove GCPs and exit the airport.

All missions will be documented by a photographer designated for each mission, from MTRI, who is not flying the sUAS or acting as an observer (this is usually one of the GCP data-collection crew members).

A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date in case any final modifications are needed.

Figures G-5 through G-8 show asphalt distress photos from the January 2021 APTech manual survey at TTF. In addition, PCI inspection map and survey results are also illustrated in Figure G-9 to G-12.



Figure G-5. Longitudinal and Transverse Cracking at RW 321 10 SU 53



Figure G-6. Depression at TWA 10 SU 25



Figure G-7. Raveling at TWA 10 SU 7



Figure G-8. Weathering at RW321 10 SU 63



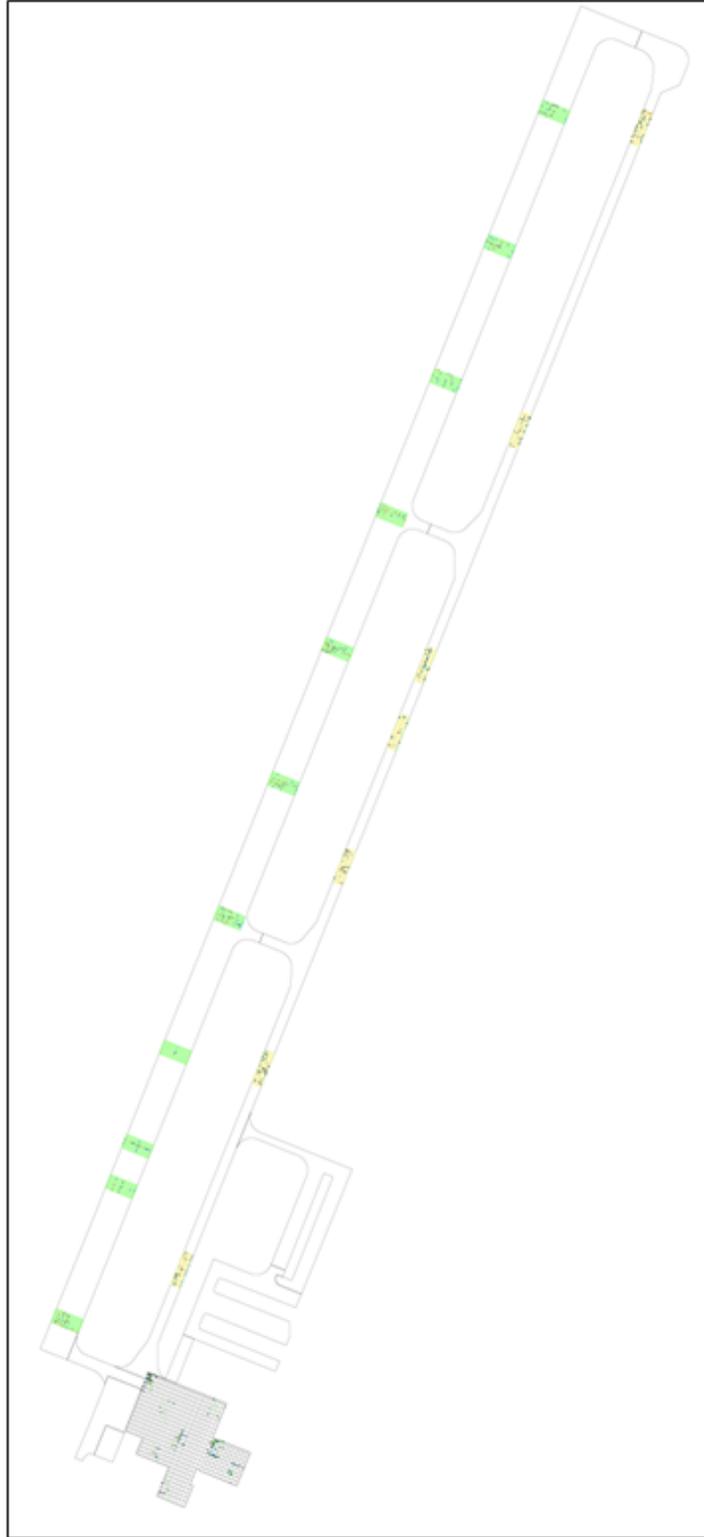


Figure G-11. Location of the Sample Units of Manual Pavement Inspection Conducted in January 2021



Figure G-12. Location and Pavement Distresses on the High-Resolution Data sUAS Collection Sample Units at TTF

G.7 REFERENCES

MDOT. (2019). *Custer Airport Pavement Management Report*.

## APPENDIX H—AIRPORT CONDITION SURVEY SAFETY PLAN FOR CUSTER AIRPORT, MONROE, MICHIGAN IN MAY 2021

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Custer Airport (TTF) in Monroe, Michigan. This document was developed along with the data collection plan provided in Appendix G. Figures H-1 and H-2 show the travel plans for the research team, and Figure H-3 highlights TTF layout and location of the ground control points (GCPs).

Data collection: May 21, 2021

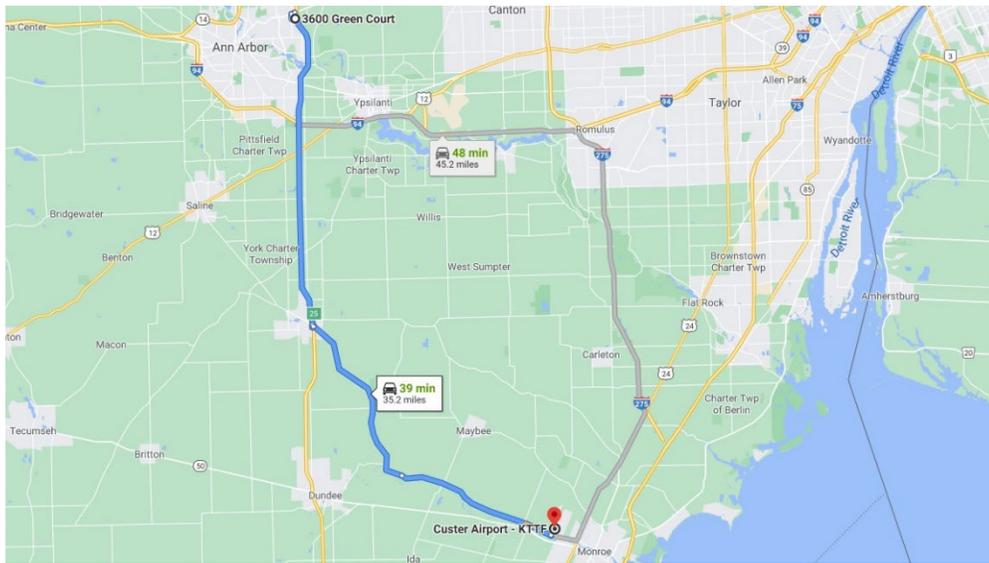


Figure H-1. Travel Route From Ann Arbor, Michigan to Custer Airport

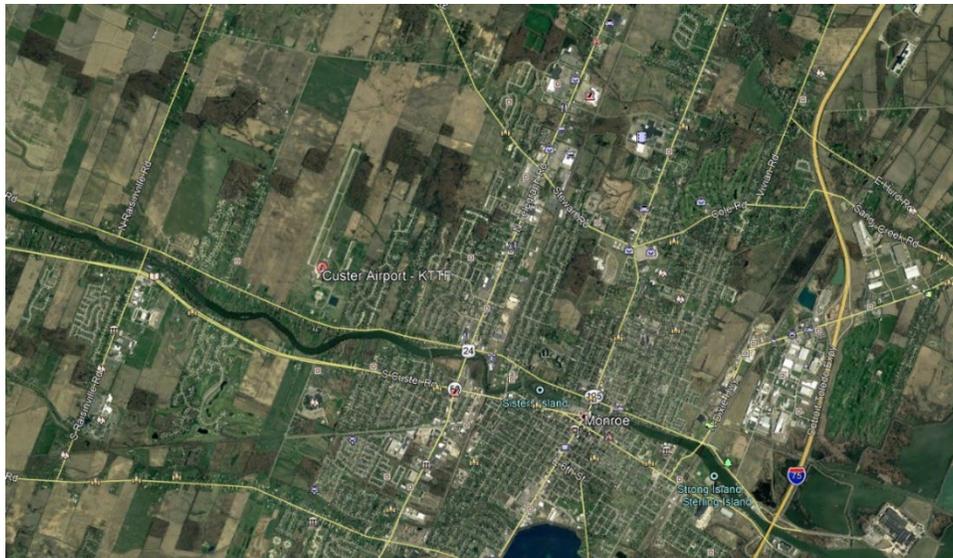


Figure H-2. Custer Airport

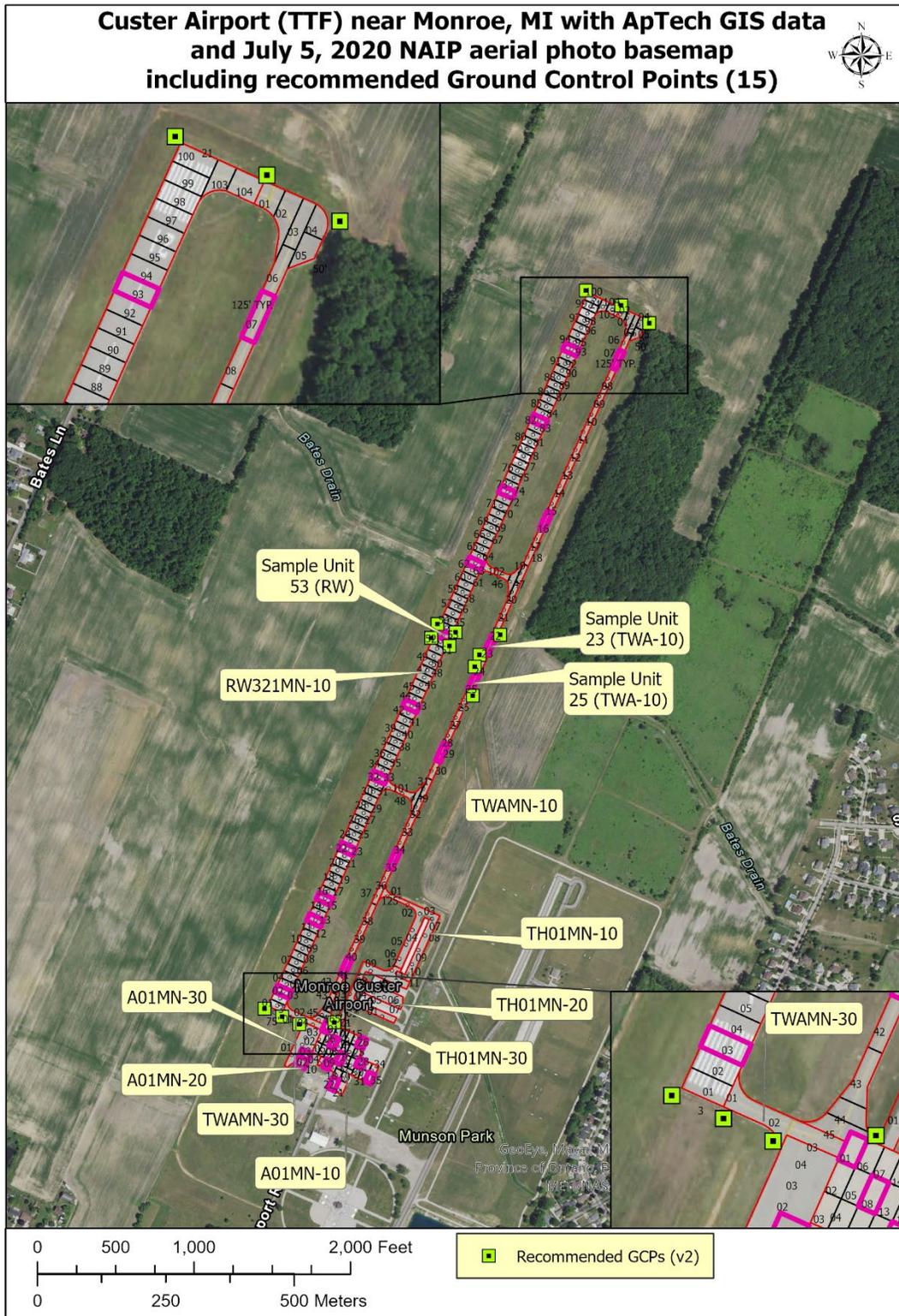


Figure H-3. Locations of Ground Control Points

## H.1 CONTACT INFORMATION

For any safety questions during field data collection, please contact:

- Richard Dobson (Lead Pilot-in-command)

Other participants are:

- Chris Cook (road and drone safety observer, backup pilot)
- Julie Carter (ground control data collector, backup road and drone safety observer)

Proposed schedule:

Will depart Michigan Tech Research Institute (MTRI) at 7:50 a.m., arriving at TTF at approximately 8:30 (travel time to Monroe from MTRI is approximately 40 minutes). Survey the airport area, pack up, and head back to the office by 3:30 p.m. this time.

## H.2 FIELD SITE

TTF is near Monroe, Michigan. The TTF airport manager is Dan Diesing, who has agreed to UAS field deployment. Dan will issue a Notice to Airmen (NOTAM) as he did for the 3/12/22 data collection, which will inform pilots that drone operations will be occurring at this General Aviation airport.

## H.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on a hard hat and reflective vest. Driving vehicles must have yellow caution lights present.

- A stand-up safety briefing will be held at the beginning of all data-collections days. After data collection, input will be sought from crew members on any safety concerns that may have come up but were not addressed.
- All crew members on the field site must wear protective clothing (hardhat, steel - or composite-toe boots, high-visibility vest, and glasses) at all times.
- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic and for the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- Crew members will operate on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway or taxiway being surveyed by UAS, crew members will cease operations (e.g., landing UAS) and continue only after the manned aircraft have finished their takeoff or landing procedures.
- The data-collection team will have two components: a UAS data-collection team and a GCP data-collection team. Each team will have their own Sporty's® 400 aviation radio, which will be on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 122.7 used for TTF.

- Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways.
- Crew members must always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members should avoid standing on runways or taxiways during data collections unless absolutely necessary.
- Crew members should avoid standing in open traffic lanes present at the airport. If walking along an open stretch of roadway, crew members should walk against the flow.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the ends of the runway is being used so the team will stay outside these areas when not completing a data collection. Team will keep away 76.2 m horizontally from any moving aircraft.

#### H.4 sUAS SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants a day prior to field collections. Briefings will include where the UAV will be operating, safe places and minimum distance to stand or work while the UAV is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a Remote Pilots Certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly. Additional safety guidelines are listed below:

- Remain a safe distance from, and do not stand directly below, a flying drone.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are being operated unless it is an immediate emergency.
- All drone operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of sUAS operation in case of a battery fire.

#### H.5 FIRST AID AND MEDICAL

- First aid kit will be on site with the field crew for all site visits.
- Emergency number is 911.
- Nearest hospital location to study site: ProMedica Monroe Regional Hospital, Monroe (4.8 km, 8 minutes): 718 N Macomb St, Monroe, Michigan 48162 Phone: (734)240-8400 (non-emergency).

- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead). Any workplace injury must be reported to Lisa, and appropriate forms filled out if medical care is sought because of any workplace injuries.

## H.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew will travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
- Field equipment will be individually assigned as much as possible (e.g., whomever starts with a particular drone will use that one throughout the day) and will be disinfected with Lysol®-type wipes when possible.
- Crew members are allowed to travel within the same vehicle when the University's Health & Safety Level is at Level 3. Level 3 requires a face covering for everyone when riding in a vehicle with more than one person. The vehicle must be sanitized between uses. Crew members who regularly travel/work together may sit up to two people per seat row; all others follow Level 4 guidance, which requires sitting in separate rows.
- As of 05/19/2021, the University is at Level 3. (<https://www.mtu.edu/flex/operations/levels/>)
- The established cleaning protocol for the MTRI Durango MUST be followed – laminated copies can be found inside the Durango.
- Fieldwork should comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
- COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>.
- Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
- Research Pandemic Checklist: Research Pandemic Checklist - Google Docs
- When the University is at Level 3, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-directors for their approval, with a cc: to Office Manager/ Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

APPENDIX I—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN  
FOR COLE COUNTY MEMORIAL AIRPORT (MTO), MATTOON, ILLINOIS IN  
JUNE 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Cole County Memorial Airport (MTO) in Mattoon, Illinois. This document is developed along with the safety plan provided in Appendix J.

Data collection: June 16 and 17, 2021

I.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with an integrated 20-megapixel (mp) camera (both) with spare batteries [charged]
- Controller [charged]
- Integrated controller [charged]
- Spare 4G Pixel™ phone as a backup controller [charged]
- DJI Mavic 2 Enterprise Advanced (M2EA) with an integrated dual 48-mp camera and a 640 x 512 thermal camera (two systems – one from Michigan Tech Research Institute [MTRI], one from Iowa State University [ISU])
- 7 M2EA batteries from MTRI, 6 batteries from Iowa State [charged]
- Smart controller for each drone [charged]
- Bergen Hexacopter with spare batteries [charged]
- Controller [charged]
- First-person view (FPV) screen [charged]
- Optical camera (Nikon D850 45.7 mp) [batteries charged]
- Tetracam micro-MCA6 multispectral imaging system [battery charged]
- mdMapper-1000+ with spare batteries [charged]
- Controller [charged]
- Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]

I.2 OTHER EQUIPMENT

- Propeller AeroPoint™ electronic Global Positioning System (GPS)-based ground control targets (10)
- Micro SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- Portable 1 TB solid-state drive (SSD)
- Folding takeoff pad
- Generator and gas can
- Rugged Olympus Tough TG-5® GPS camera (12 mp) - (for geolocated field photos) (1) [charged]
- Sony Alpha camera (16 mp) for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least 2 copies), pre-filled out with information for documenting flight details

- Sporty’s® SP-400 (2) and Yaesu® FTA 750L (1) aviation radios, tuned to TTF Unicom frequency 122.7 for the entire time the team is onsite at MTO
- One aviation radio is provided for every two-person sUAS flight team—two teams and two aviation radios total. The third aviation radio is for the person(s) placing GCPs or moving on the airfield so that they can operate in separate parts of the airport, completing needed tasks more quickly while maintaining safety and awareness of manned and unmanned aircraft operations on or near MTO.
- MTRI anemometer (for wind speed checking)
- MTRI iPad® Mini with GeoPDF airport map that includes recommended ground control point (GCP) locations to assist with placing GCPs
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- High-vis vests, hardhats, and protective eyewear
- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of MTRI safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled water
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed the day prior to travel to Mattoon, Illinois.

### I.3 AIRPORT CONTACT INFORMATION

The MTO Airport manager is Andrew Fearn (217-234-7120). Ms. Laura from APTech made initial contact with Mr. Fearn on June 7, 2021, and Dr. Halil Ceylan contacted him on June 9, 2021, regarding the sUAS data collection plan at his airport. Mr. Fearn welcomed the research team and kept in close contact with Dr. Ceylan via email and phone calls.

- Airport webpage: <https://www.colescountyairport.com/>
- SkyVector webpage about MTO: <https://skyvector.com/airport/MTO/Coles-County-Memorial-Airport>

### I.4 FOCUS AREAS FOR DATA COLLECTION

Data collection will focus on the complete Runway 6/24, Taxiway D (D, D3, and D4), and Apron R section 3 at MTO. The runway has six different sections with a mix of asphalt overlay over asphalt concrete (AAC), asphalt overlay over Portland cement concrete (APC), and Portland

cement concrete (PCC) pavements. The dimensions of the runway are 5,799 ft x 100 ft or 1,768 m x 30.5 m. According to a pavement inspection survey conducted by our collaborators Applied Pavement Technology, Inc. (APTech) in 2019 for MTO, the AAC and APC pavement of the runway had depression, longitudinal and transverse (L&T) cracking, weathering, and block cracking with a pavement condition index (PCI) value ranging from 61 to 86. In addition, the PCC pavement contained alkali-silica reaction (ASR), joint spalling, joint seal damage, large patch, longitudinal, transverse, and diagonal (LTD) cracking, pop-outs, and small patch with a PCI value of 42. A detailed descriptions of the distresses inspected in MTO are provided in Table I-1.

Table I-1. The PCI Survey Result of the Data Collection Area

Branch ID	Section ID	Surface Type	2019 PCI	Type of Distresses	Inspected SU out of total SU
6	1	AAC	65	Depression, L&T cracking, weathering	7/44
6	2	AAC	86	L&T cracking, weathering	4/8
6	3	APC	83	L&T cracking, weathering	4/6
6	4	PCC	42	ASR, joint spalling, joint seal damage, large patch, LTD cracking, pop-outs, small patch	3/3
6	5	AAC	62	Block cracking, L&T cracking, weathering	5/18
6	6	AAC	61	Block cracking, L&T cracking, weathering	6/24
D3	1	AAC	21	alligator cracking, block cracking, L&T cracking, raveling	2/2
D4	1	AAC	33	Alligator cracking, block cracking, weathering	2/2
D	1	AAC	36	alligator cracking, block cracking, L&T cracking, weathering	4/7
D	2	AAC	36	Alligator cracking, block cracking, L&T cracking, weathering	6/21
D	3	APC	35	Block cracking, joint reflection cracking, weathering	1/1
D	4	PCC	55	Joint seal damage, LTD cracking, shattered slab, shrinkage cracking	1/1
D	5	PCC	84	Joint seal damage, LTD cracking, shrinkage, cracking	2/2
R	3	AAC	69	L&T cracking, shoving, weathering	5/10

AC= Asphalt concrete pavement

PCC= Portland cement concrete pavement

AAC= Asphalt overlay over asphalt concrete

APC= Asphalt overlay over Portland cement concrete

L&T cracking = Longitudinal and transverse cracking

LTD cracking = Longitudinal, transverse, and diagonal cracking

Conversely, Taxiway D has three parts: D, D3, and D4, with a total of 7 sections. Like Runway 6/24, Taxiway D also has a mix of AAC, APC, and PCC pavements with a total length of 1,460 ft and a width of 50 ft. The combined surface area of the Taxiway D, D3, and D4 is 73,000 square ft or 6,782 square m. Alligator cracking, block cracking, L&T cracking, raveling, joint reflection cracking, and weathering were presented on the AAC and APC pavement. The PCI value for different sections of the AAC and APC pavement ranged from 21 to 36. There were two PCC pavements on the Taxiway D: DMTO-04 and DMTO-05 with PCI values of 55 and 84, respectively. Joint seal damage, LTD cracking, shattered slab, and shrinkage cracking were present on those sections during the pavement inspection conducted by our research team as part of a contract between MTO and APTEch in 2019.

The Apron R Section 3 is an AAC pavement with a length of 480 ft (146 m), a width of 100 ft (30.5 m), and an area of 48,000 square ft or 4,459 square m. It had L&T cracking, shoving, and weathering, and a PCI value of 69 in 2019.

The focus will also be on high-resolution red, green, blue (RGB) optical and thermal data collection from five sample units. Three PCC sample units are in Runway 6/24 Section 4 (Sample units 1, 2, and 3). All three sample units were inspected by APTEch in 2019, and the measured PCI value was 42, as shown in Table I-1. The sample units had ASR, joint spalling, joint seal damage, large patch, LTD cracking, pop-outs, and small patch. In addition, two sample units of the D3MTO-01 are selected for AAC pavement inspection, which had Alligator Cracking, Block Cracking, L&T Cracking, and Raveling with a PCI value of 21. The total area of the five sample units is 39,950 sq. ft or 3711 m<sup>2</sup>. The details of the high-resolution sample units are provided in Table I-2. In addition, their locations as well as the MTO layout are provided in Figures I-1 and I-2.

Table I-2. PCI Survey Result of the High-resolution Sample Unit

Branch ID	Section ID	Surface Type	2019 PCI	Type of Distresses	Inspected SU out of Total SU	Inspected Sample Units	Section Area (m <sup>2</sup> )	Inspected Area (m <sup>2</sup> )
6	4	PCC	42	ASR, joint spalling, joint seal damage, large patch, LTD cracking, pop-outs, small patch	3/3	1, 2	3307.2	2787.1
D3	1	AAC	21	Alligator cracking, block cracking, L&T cracking, raveling	2/2	1, 2, 3	953.0	924.4
D4	1	PCC	55	LTD cracking, joint seal damage, shattered slab, shrinkage cracking	1/1	1	929.0	929.0

PCC= Portland cement concrete pavement  
AAC= Asphalt overlay over asphalt concrete  
L&T cracking = Longitudinal and transverse cracking  
ASR= Alkali-silica reaction  
LTD cracking = Longitudinal, transverse, and diagonal cracking



Figure I-1. Overview of MTO and Sampling Focus Areas, Including Recommended Locations for Ground Control Points



Figure I-2. Recommended Locations for Ground Control Points

## I.5 OBJECTIVES FOR UPCOMING JUNE 2021 UAS DATA COLLECTION

### I.5.1 Mavic 2 Pro

Optical imagery is planned to be collected at 15.2 m above ground level (AGL) with Mavic 2 Pro 20 mp for the complete Runway 6/24, Taxiway D (D, D3, and D4), and Apron R section 3. MTRI is planning to bring 2 Mavic 2 pro sUAS with additional batteries. A total of at least seven preplanned missions are likely needed to cover the runway, taxiway, apron, and the pavements connecting them.

The flight plans for these missions are created with the Pix4D Capture Android application, which has been successfully used in mission planning for previous research data. An 80% forward overlap and a 70% side overlap will be used, which is standard for most of the missions in which close-range photogrammetry software is used to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully for creating outputs for different flights at Custer Airport (TTF), Monroe, Michigan and Grosse Ile Municipal Airport (ONZ), Grosse Ile Township, Michigan. Figures I-3, I-4, and I-5 show drafts of the preplanned missions for a runway mission at 15.2 m using the Mavic 2 Pro sUAS.

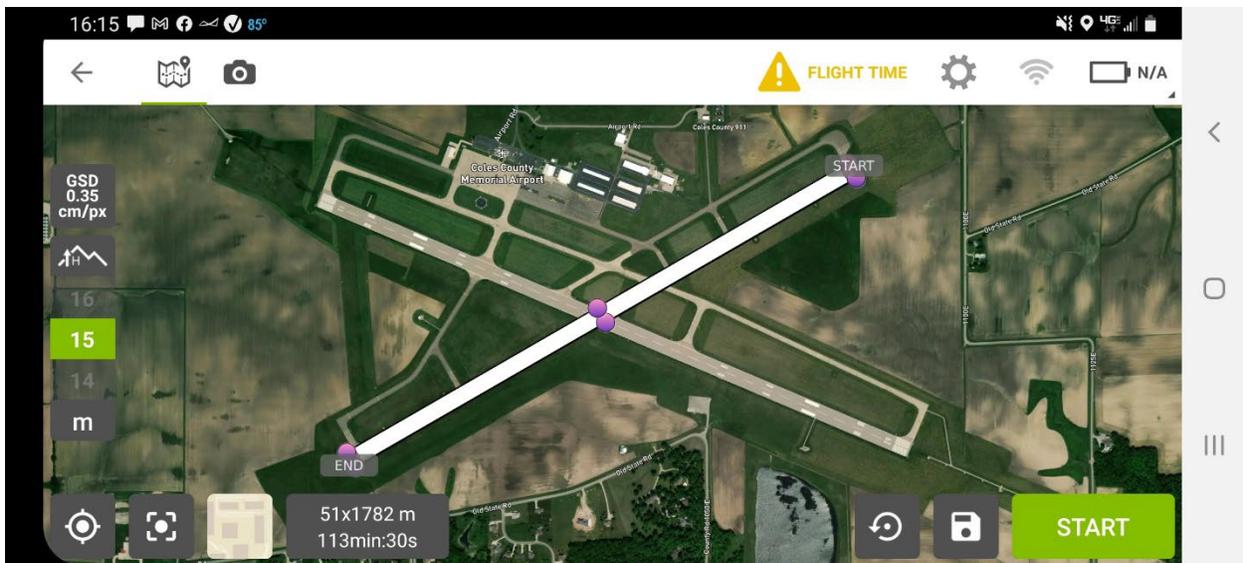


Figure I-3. Mavic 2 Pro Flight Plan for Runway 6/24

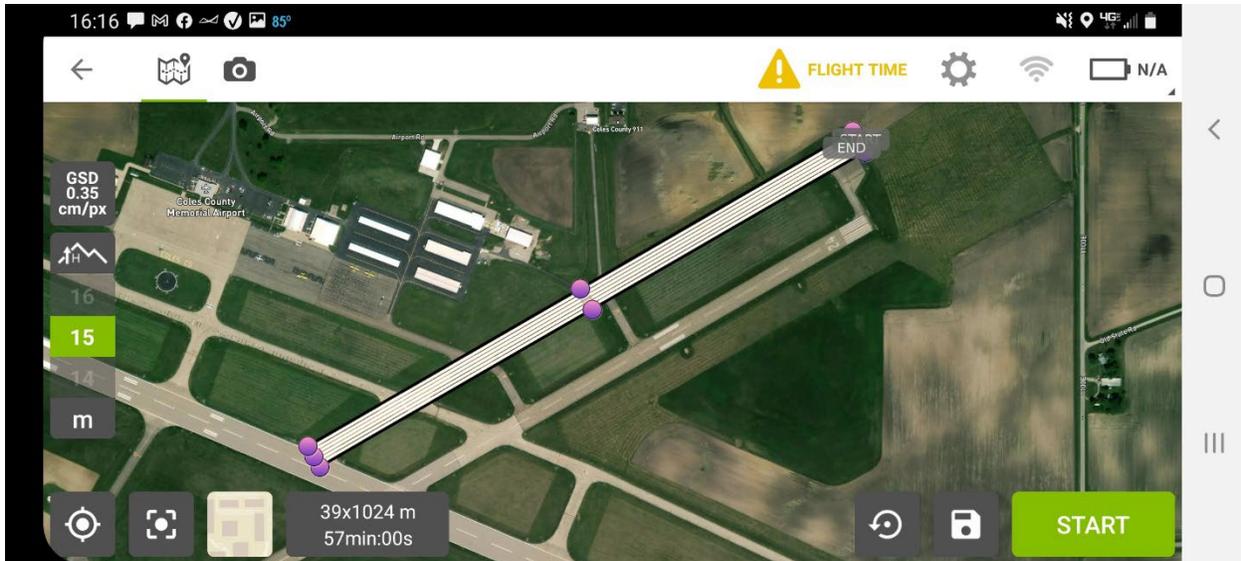


Figure I-4. Mavic 2 Pro Flight Plan for Taxiway D



Figure I-5. Mavic 2 Pro Flight Plan for Apron R Section 3

### I.5.2 Mavic 2 Enterprise Advanced

Optical and thermal imageries will be collected over the sample units using Mavic 2 Enterprise Advanced (M2EA). Four preplanned flights will be required to collect this data. Two M2EA units will be available, one with seven batteries and one with six batteries. Batteries can be recharged during the day with an available generator. The average flight time is estimated at 20 minutes per battery. The optical RGB data will be collected from 15.2 m AGL and stereo thermal data from 24.4 m AGL. The preplanned flights are shown in Figures I-6 and I-7.

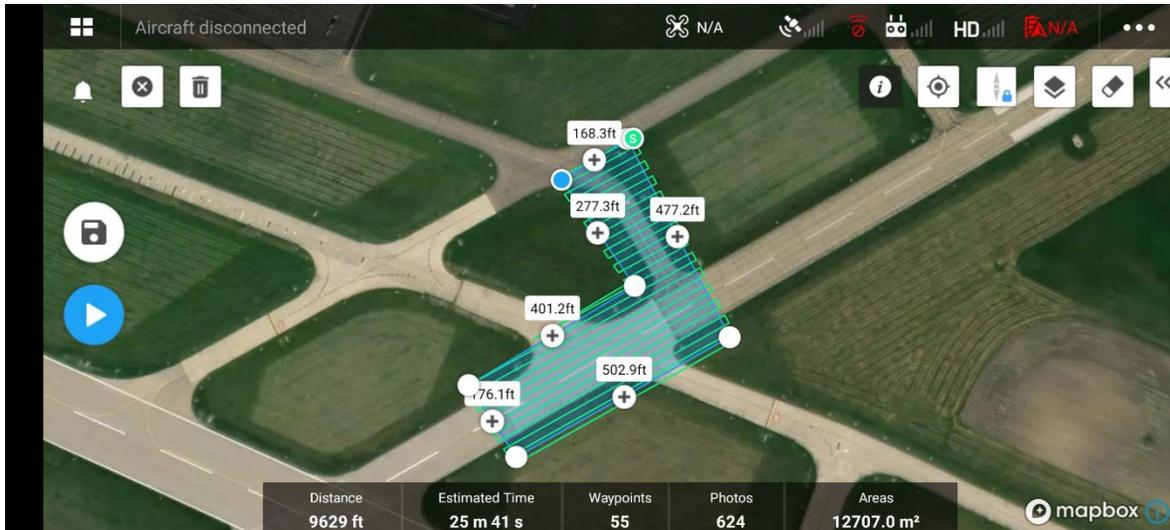


Figure I-6. Flight Plan for Optical RGB Data Collection with Mavic 2 Enterprise Advanced Over Five High-Resolution Sample Units

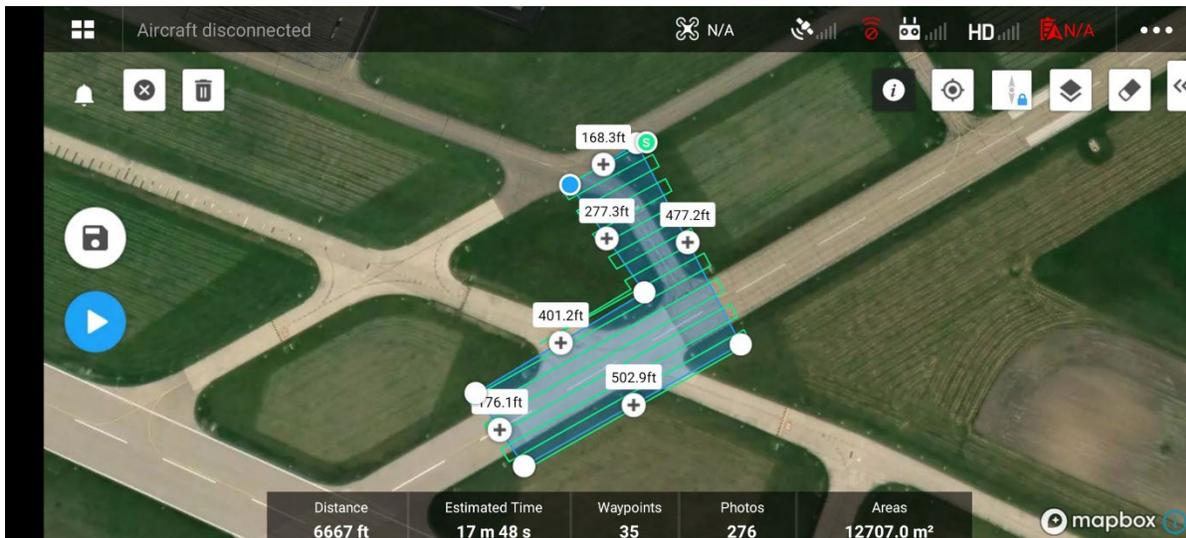


Figure I-7. Flight Plan for Stereo Thermal Data Collection with Mavic 2 Enterprise Advanced Over Five High-Resolution Sample Units

### I.5.3 Bergen Hexacopter

The Bergen Hexacopter will be flown manually to collect optical imageries at 18.3 m on June 17, 2021 from the five selected sample units of the runway and taxiway. The focus will be on collecting Optical RGB data using a Nikon D850 45.7-mp camera. Because of the closeness of the five selected sample units, they will be covered in two manual flights. Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired sample units are. At 60 feet, the RGB optical imagery will be 1.5 mm (0.06 in) resolution. Manual control is planned because of the small areas planned for data collection and the older Bergen flight control hardware and software not being compatible with current mission planning apps. Flight details are provided in Table I-3.

### I.5.4 mdMapper-1000+

The team also has a German-made mdMapper-1000+ UAS that is used for photogrammetric optical data collection. The mdMapper-1000+ was purchased in 2020 to help detect map defects on bridge decks and measure 3D rates of construction progress. This system has been flown at 18.3 m and 30.5 m AGL with lesser winds and turbulence at TTF in Monroe, Michigan. The mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 100 feet, the optical imagery will have a 5-mm (0.2 in.) resolution.

Table I-3. Planned Sensors and Flying Heights for All sUAS

Date	Target Area	sUAS Platform	Sensors	AGL (m)	Approximate Resolution (mm/pix)
6/17	TWD3MTO-01 SU 1 and 2, TWD4MTO SU 1, RW 6MTO-04 SU 1, 2, and 3	Bergen Hexacopter	45.7-mp optical RGB Nikon D850	18.3	1.5
		M2EA	48-mp optical RGB + 512 x 640 thermal	15.2	2.5
		M2EA	*48-mp optical RGB + 512 x 640 thermal	24.4	3.1
		mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	30.5	5
6/18	Runway 6/24	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
6/18	Taxiway D	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
6/18	Apron 3	Mavic 2 Pro	20-mp optical RGB	15.2	3.7

M2EA will be flown for stereo thermal data collection

AGL = Above Ground Level

The M2EA RGB thermal camera is not true 48 mp.

### I.6 PILOTS AND SUPPORT TEAM

The research team has four research staff available for flying the sUAS, all of whom have a current Part 107 Unmanned Pilot's Certificate. There are other crew members who can help with ground control point GPS data collection and capturing pavement distress images. Standard procedure is to have at least two staff members for each UAS flight: one sUAS pilot and one safety observer. In simultaneous data collection, each sUAS pilot will have a dedicated field observer.

*Provisional timeline for data collection day – All timing is subject to change based on weather conditions and airport operations.*

The research team will travel to Mattoon, Il, from Iowa and Michigan on June 15, 2021. MTO requires all personnel driving inside the airport to complete a 90-minute training, which will be done on June 16, 2021. After placing the GCPs, the research team will focus on collecting thermal and optical of the sample units. If time allows, the complete runway, taxiway, and apron data collection will be conducted on the same day. Otherwise, the remaining data will be collected on

June 17, 2021. Downtime will accommodate battery/sensor swaps and remain grounded while aircraft operate in the vicinity.

The data collection team will have their aviation radio on at all times for data collections on Unicom frequency 122.7, used for MTO. Communications via the radio should be in the form of “Cole County, Mattoon. [Announcement]. Cole County, Mattoon” as done in the previous sUAS data collection.

Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data collection conversations, battery charging, and checking data collection, outside the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends is being used, so the team will stay outside these areas when not completing a data collection. The team will keep 76.2 m horizontally from any moving aircraft. The team will not operate UAS if wind gusts exceed 24.1 kph and temperature above. A hand-held anemometer will be used to measure wind speed before each mission.

Below is the planned data collection timeline:

### **June 16, 2021**

- 8:00 AM – 9:30 AM: Driver training
- 9:30 AM – 10:00 AM: AeroPoints and Ground Control Points based on the ground control placement map
- 10:00 AM – 5:00 PM:
- Mavic 2 Pro data collection
  - Runway 6/24 is 5,799 ft x 100 ft
    - Estimated Flight Time to only collect imagery: 1.9 hours
    - Estimated Total Time to Collect Full Runway: 2.9 hours (6 flights needed)
  - Taxiway D is 3,282 ft x 50 ft
    - Estimated Flight Time to only collect imagery: 1 hour
    - Estimated Total Time to Collect Full Runway: 1.5 hours (3 flights needed)
  - Taxiway D Connector
    - Estimated Flight Time to only collect imagery: 33 mins
    - Estimated Total Time to Collect Connectors: 50 mins (3 flights needed)
  - Apron is 542 ft x 117 ft
    - Estimated Flight Time to only collect imagery: 14 minutes
  - Taxiway D Section 3 - 182 ft x 50 ft
    - Estimated Flight Time to only collect imagery: 2 minutes
  - Runway 6/24 Section 4 - 322 ft x 100 ft
    - Estimated Flight Time to only collect imagery: 5 minutes

- Taxiway D Section 3 - 250 ft x 50 ft (Optional)
      - Estimated Flight Time to only collect imagery: 3 minutes
- 5:00 PM – 5:30 PM: Ground control points collection and data collection conclusions

**June 17, 2021**

- 8:00 AM – 8:30 AM: 10 AeroPoints placement based on the ground control placement map
- 8:30 AM – 3:00 PM: Sample unit’s data collection
  - Microdrones md4-1000+
    - Taxiway D Section 3 - 182 ft x 50 ft, Runway 6/24 Section 4 - 322 ft x 100 ft, and Taxiway D Section 3 - 250 ft x 50 ft (All in one flight)
      - Estimated Flight Time to only collect imagery: 17 minutes
  - Bergen Hexacopter with Nikon D850
    - Taxiway D Section 3 - 182 ft x 50 ft
      - Estimated Flight Time to only collect imagery: 2 minutes
    - Runway 6/24 Section 4 - 322 ft x 100 ft
      - Estimated Flight Time to only collect imagery: 5 minutes
    - Taxiway D Section 3 - 250 ft x 50 ft (Optional)
      - Estimated Flight Time to only collect imagery: 3 minutes
  - Mavic 2 Enterprise Advanced
    - Taxiway D Section 3 - 182 ft x 50 ft, Runway 6/24 Section 4 - 322 ft x 100 ft, and Taxiway D Section 3 - 250 ft x 50 ft (All in one flight) (Optical RGB)
      - Estimated Flight Time to only collect imagery: 36 mins.
      - Estimated Total Time to Collect Connectors: 41 mins (2 flights needed)
    - Taxiway D Section 3 - 182 ft x 50 ft, Runway 6/24 Section 4 - 322 ft x 100 ft, and Taxiway D Section 3 - 250 ft x 50 ft (All in one flight) (stereo thermal)
      - Estimated Flight Time to only collect imagery: 25 mins
      - Estimated Total Time to Collect Connectors: 30 mins (2 flights needed)
- 3:00 PM – 3:30 PM: AeroPoints collection and data collection conclusion

The data-collection schedule is developed based on the weather condition shown on the forecast. The small Mavic 2 sUASs are less susceptible to wind speed and gust, so the plan is to collect data using smaller sUAS on Wednesday.



Figure I-7. Weather Forecast for Mattoon, Illinois

All missions will be documented by a photographer designated for each mission. The photographer will be a separate crew member who is not flying the UAS or acting as an observer (this is usually one of the GCP data collection crew members).

A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date if any final modifications are needed.

APPENDIX J—AIRPORT CONDITION SURVEY SAFETY PLAN FOR COLE COUNTY MEMORIAL AIRPORT, MATTOON, ILLINOIS IN JUNE 2021

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Cole County Memorial Airport (MTO), in Mattoon, Illinois. This document was developed along with the data collection plan provided in Appendix I. Figures J-1 and J-2 show the travel plans for the research team, and Figures J-3 and J-4 highlight MTO layout.

Data collection: June 16 and 17, 2021

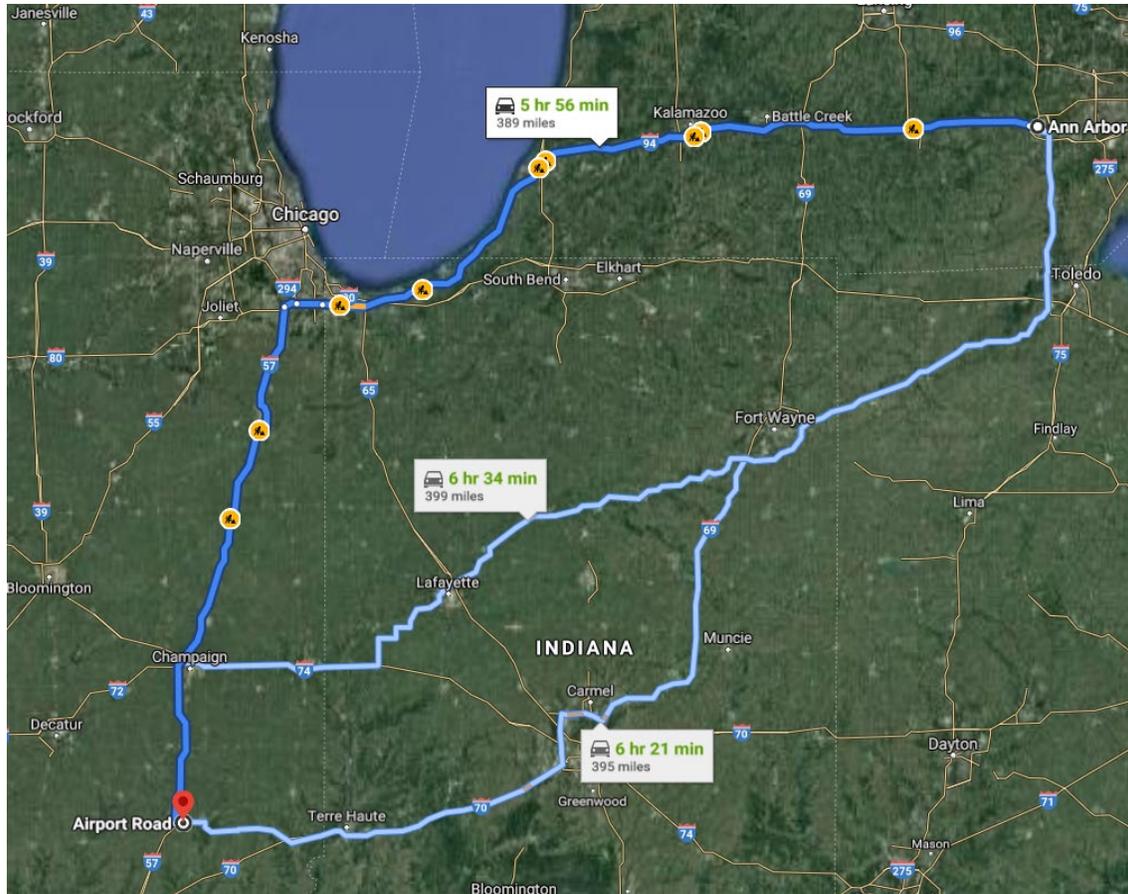


Figure J-1. Travel Route from Ann Arbor, Michigan to Mattoon, Illinois

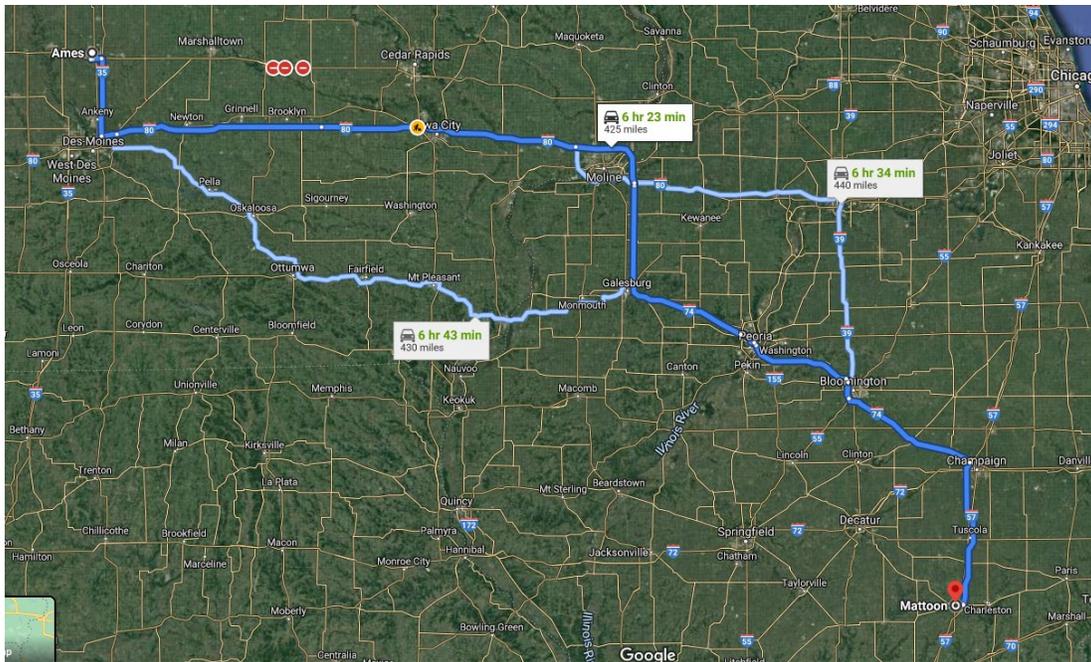


Figure J-2. Travel Route from Ames, Iowa to Mattoon, Illinois

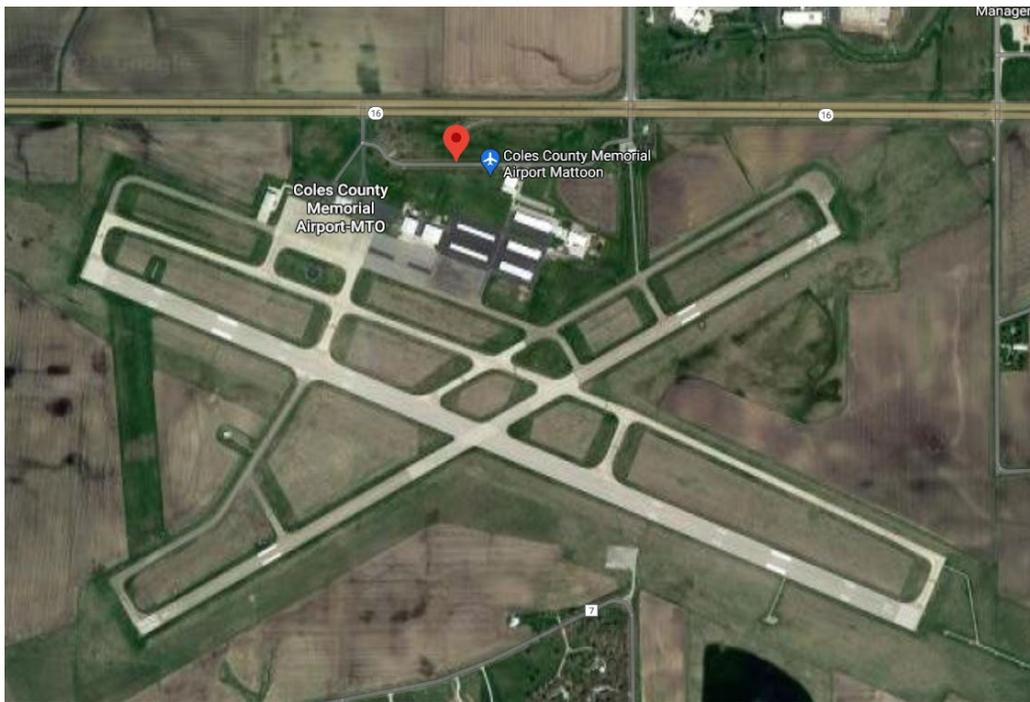
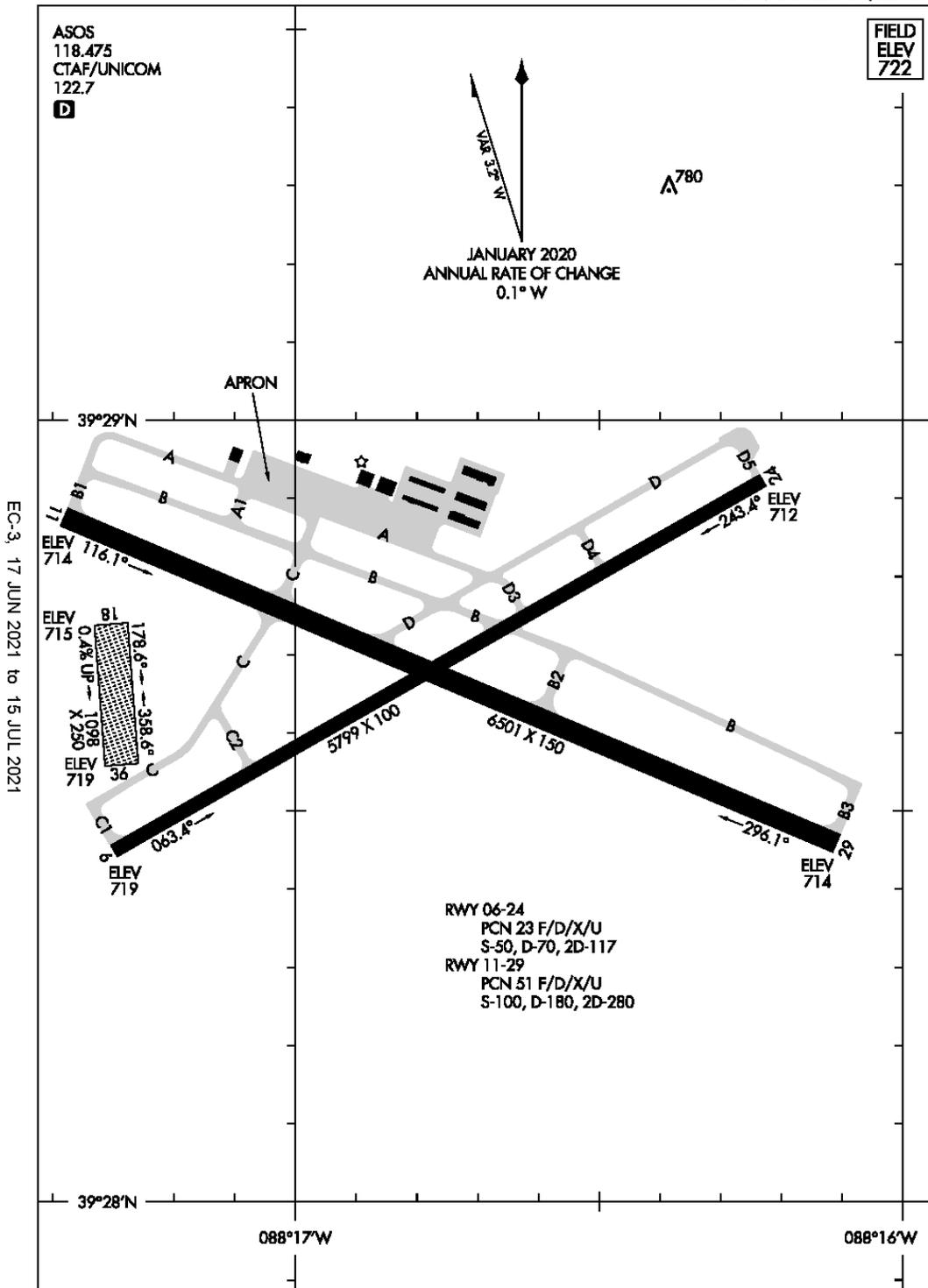


Figure J-3. View of MTO, in Mattoon, Illinois

21112  
**AIRPORT DIAGRAM**

AL-5180 (FAA)

**COLES COUNTY MEML (MTO)**  
 MATTOON/CHARLESTON, ILLINOIS



EC-3, 17 JUN 2021 to 15 JUL 2021

EC-3, 17 JUN 2021 to 15 JUL 2021

**AIRPORT DIAGRAM**  
 21112

**COLES COUNTY MEML (MTO)**  
 MATTOON/CHARLESTON, ILLINOIS

Figure J-4. Airport Diagram of MTO, Mattoon, Illinois

## J.1 CONTACT INFORMATION

For any safety questions during field data collection, please contact:

- Halil Ceylan, Iowa State University (ISU) (Project PI and Lead)
- Colin Brooks, Michigan Tech research Institute (MTRI) (Project Lead) (Also a backup pilot, ground control collector)
- Richard Dobson (Lead Pilot-in-command)

Other participants are:

- Chris Cook, MTRI (road and drone safety observer, backup pilot)
- Abdullah Sourav, ISU (drone pilot)
- Julie Carter, MTRI (ground control data collector, backup road & drone safety observer)
- David Peshkin, Applied Pavement Technology, Inc. (APTech) (APTech Project Lead)

Proposed schedule:

- ISU team will depart Ames, Iowa at 1 p.m. on June 15, 2021, arriving in Mattoon approximately 9 p.m. local time (travel time to Mattoon from Ames is approximately 6 hours and 30 minutes).
- MTRI team will depart MTRI at 4 p.m. on June 15, 2021, arriving in Mattoon approximately 10 p.m. local time (travel time to Mattoon from MTRI is approximately 6 hours minus the time change).
- Survey the airport on June 16 and 17, 2021 as needed
- Return to Ames, Iowa on June 17 or 18, 2021, leaving by 4 p.m. local time
- Return to MTRI on June 17, 2021, leaving by 4 p.m. local time

## J.2 FIELD SITE

MTO is located outside of Mattoon, Illinois. The MTO airport manager is Andrew Fearn, who has agreed to UAS field deployment. The general phone number for the airport is 217-234-7120.

## J.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on a hard hat and reflective vest. Driving vehicles must have yellow caution lights present. Additional safety guidelines are listed below.

- A stand-up safety briefing will be held at the beginning of any data-collections days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (hardhat, steel- or composite-toe boots, high-visibility vest, glasses) at all times.

- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic and for the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- The team will be operating on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway or taxiway being surveyed by sUAS, operations (land sUAS) will be ceased, then continued after the manned aircraft have finished their takeoff or landing procedures.
- The data-collection team will have two sUAS data-collection teams, with Richard Dobson (MTRI) and Abdullah Sourav (ISU) as the lead pilots for each team. Each team will have their own Sporty's® 400/ YEASU Spirit aviation radio, which will be on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 122.7 used for MTO.
- AeroPoint™ ground control points (GCPs) will be placed at the beginning of each data-collection day, with Julie Carter and Colin Brooks taking care of this. Additional traditional cloth targets will be placed at the beginning of the first day and have their locations recorded with a decimeter-resolution Global Positioning System (GPS). Both sets of targets will be placed off the runways.
- Windows of moving vehicles will be kept open, with vehicle radios off, to enable listening for unexpected aircraft when driving on runways and taxiways.
- Crew members should always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members should avoid standing on runways or taxiways during data collections unless necessary.
- Crew members should not stand in open traffic lanes present at the airport. If walking along an open stretch of roadway, walk against the flow.

As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 m from the runway centerline and 304.8 m from the ends of the runway is being used, so the team will stay outside these areas when not completing a data collection. The team will keep away 76.2 meters horizontally from any moving aircraft.

#### J.4 sUAS SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants a day prior to field collections of where the sUAS will be operating, the location of safe places, the minimum distance to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a remote pilot's certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly. Other safety guidelines include:

- Remain a safe distance from, and do not stand directly below, a flying sUAS.

- DO NOT attempt to distract the pilot or designated spotters while the sUASs are being operated unless it is an immediate emergency.
- All sUAS operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of sUAS operation in case of a battery fire.

## J.5 FIRST AID AND MEDICAL

First aid kit will be on site with the field crew for all site visits.

Emergency number is 911.

Nearest hospital location to study site: Sarah Bush Lincoln Health Center, Mattoon (0.8 km, 1 minutes).

1000 Health Center Drive, Mattoon, Illinois 61938. Phone: 217-258-2525 (non-emergency).

MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead). Any workplace injury must be reported to Lisa, and appropriate forms filled out if medical care is sought because of any workplace injuries.

ISU phone number: (515)-294-8213, Paul Kremer (Manager Research, CCEE, ISU). Any workplace injury must be reported to Mr. Kremer if medical care is sought because of any workplace injuries.

## J.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

**Notes:** Most states have lifted COVID-19 restrictions. More information on Illinois COVID-19 guidance is available at: <https://coronavirus.illinois.gov/s/> and <https://www.dph.illinois.gov/covid19/community-guidance/mask-use>. A news summary is available at <https://www.nbcchicago.com/news/local/illinois-phase-5-here-are-the-guidelines-for-reopening-this-week/2526840/>.

### J.6.1 ISU's COVID-19 Safety Plan

- The COVID-19 guidelines have been updated for regent institutions in Iowa on May 20, 2021. Mask use continues to be encouraged for those who have not been vaccinated and is optional for those who have been vaccinated.
- Travelers has been encouraged to adhere to CDC guidance for domestic travel.
- The team will follow the rules outlined by the Iowa State University Transportation Services while operating the vehicle and will properly clean inside the vehicle while returning.
- All details are available at the following web addresses provided below:
- COVID-19 guideline update for regent institutions in Iowa: <https://www.iowaregents.edu/news/board-news/statement-from-president-mike-richards-lifting-regents-state-of-emergency>
  - ISU safety and health policy resources: <https://web.iastate.edu/safety/>
  - ISU safety policy on COVID-19: <https://web.iastate.edu/safety/updates/covid19>

- ISU gathering and events policy: <https://web.iastate.edu/safety/updates/covid19/events-gatherings>
  - ISU Civil, Construction, and Environmental Engineering (CCEE) safety resources: <https://www.ccee.iastate.edu/safety/>
  - ISU CCEE research and instructional labs and fieldwork safety policies: <https://www.ccee.iastate.edu/files/2019/07/CCEE-Laboratory-Policies-and-Guidelines-CCEE-Safety-and-Health-Committee-and-EHS-Reviewed-and-Approved-2.23.2-3.pdf>

### J.6.2 MTRI's COVID-19 Safety Plan

MTRI's COVID-19 safety plans are as follows, and unvaccinated participants are expected to follow them:

- Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew will travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
- Field equipment will be individually assigned as much as possible (for example, whomever starts with a particular sUAS will use that one throughout the day) and will be disinfected with Lysol<sup>®</sup>-type wipes when possible.
  - Multiple workers are allowed to travel within the same vehicle when the University's Health & Safety Level is at Level 2.
  - As of June 9, 2021, the University is at Level 2. (<https://www.mtu.edu/flex/operations/levels/>)
  - The established cleaning protocol for the MTRI Durango MUST be followed—laminated copies can be found inside the Durango.
  - Work is to comply with the Michigan Tech COVID-19 Fieldwork Protocol and Safety Checklist found at the locations shown below:
- COVID-19 Research FAQs:
 

<https://www.mtu.edu/research/covid-19/faqs.html>
- Current campus health and safety level:
 

<https://www.mtu.edu/flex/operations/levels/>
- Research Pandemic Checklist: Research Pandemic Checklist - Google Docs
- Now that the University is back at Level 2, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX K—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN FOR BOONE MUNICIPAL AIRPORT, BOONE, IOWA IN JUNE 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Boone Municipal Airport (BNW) in Boone, Iowa. This document is developed along with the safety plan provided in Appendix L.

Data Collection Date: Wednesday, June 29 and Thursday, June 30, 2021 (weather permitting)

### K.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with integrated 20-megapixel (mp) camera (both) with spare batteries [charged]
  - Controller [charged]
  - Integrated controller [charged]
  - Spare 4G Pixel™ phone as a backup controller [charged]
- DJI Mavic 2 Enterprise Advanced with integrated dual 48-mp camera and 640 x 512 thermal camera (two systems – one from Michigan Tech Research Institute (MTRI) and one from Iowa State University (ISU))
  - Seven M2EA batteries from MTRI, six batteries from ISU [charged]
  - Smart controller for each drone [charged]
- Bergen Hexacopter with spare batteries [charged]
  - Controller [charged]
  - First-person view (FPV) screen [charged]
  - Optical camera (Nikon D850 45.7 mp) [batteries charged]
- Tarot x6 v2.2 with spare batteries [charged]
  - Controller [charged]
  - FPV screen [charged]
- mdMapper-1000+ with spare batteries [charged]
  - Controller [charged]
  - Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]

### K.2 OTHER EQUIPMENT

- Propeller AeroPoint™ electronic Global Positioning System (GPS)-based ground control points (GCPs) (20)
- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- 2xPortable 1 TB solid-state drive (SSD)
- 256 GB pendrive
- Folding takeoff pad
- Generator and gas can

- Rugged Olympus Tough TG-5<sup>®</sup> GPS camera (12 mp) - (for geolocated field photos) (2) [charged]
- Sony Alpha Camera (16 mp) for field photos (with zoom lens) (1) [charged]
- MTRI flight logging form (at least 2 copies), completed with information for documenting flight details
- Sporty's<sup>®</sup> SP-400 (2) and Yaesu<sup>®</sup> FTA 750L (1) aviation radios, tuned to TTF Unicom frequency 123.0 for the entire time the team is onsite at MTO
- Two aviation radios for every two-person sUAS flight team. A third radio is provided for the person(s) placing GCPs or moving on the airfield so that they can operate in separate parts of the airport, completing needed tasks more quickly while maintaining safety and awareness of manned and unmanned aircraft operations on or near BNW.
- MTRI anemometer (for checking wind speed)
- MTRI iPad<sup>®</sup> Mini with GeoPDF airport map that includes recommended GCP locations to assist with placement
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- Appropriate clothing and protective eyewear
- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of the safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled water
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed the day prior to travel to Boone, Iowa.

### K.3 AIRPORT CONTACT INFORMATION

BNW Airport manageris Dale Farnham (515 291-5094). Dr. Ceylan sent Mr. Farnham an email regarding sUAS data collection at BNW on June 16, 2021. ISU graduate student Mr. Abdullah Sourav met Mr. Farnham on June 25, 2021 and confirmed the research team's June16, 2021 visit to the airport. Dr. Ceylan communicated with Mr. Farnham regarding this data collection as well.

- Airport webpage: <https://www.farnhamaviation.com/>
- SkyVector webpage about BNW: <https://skyvector.com/airport/BNW/Boone-Municipal-Airport>

#### K.4 FOCUS AREAS FOR DATA COLLECTION

Data collection will focus on the complete Runway 15/33; Taxiway 1; T-hangar 1, Sections 1, 2, and 3; and T-hangar 2, Section 2 at BNW (Figures K-1 and K-2). The runway has two sections with Portland cement concrete (PCC) pavements. The dimensions of the runway are 4,808 ft x 75 ft or 1,465 m x 23 m. According to a pavement inspection survey conducted by APTEch for Iowa Department of Transportation (Iowa DOT) in 2018 for BNW, the Runway 15/33 section 1 had corner spalling and joint seal damage with a pavement condition index (PCI) value of 95 (Iowa DOT, 2018). In addition, the PCC pavement of Runway 15/33 Section 2 contained alkali-silica reaction (ASR), corner spalling, joint seal damage, joint spalling, large patch, LTD cracking, pop-outs, and small patch with a PCI value of 76. Details of this pavement inspection results are provided in Table K-1.

Taxiway 1 of BNW has six sections with PCI values ranging from 89 to 97 and is in very good condition. The notable PCC distresses found on the Taxiway 1 are ASR, corner spalling, joint seal, damage, joint spalling, longitudinal, transverse and diagonal (LTD) cracking, and shrinkage cracking.

T-hangar 1 has three sections. Sections 1 and 2 are asphalt concrete (AC) pavement with PCI values of 43 and 61 in 2017, respectively. Alligator cracking, longitudinal and transverse (L&T) cracking, swelling, and weathering were found on T-hangar 1. The T-hangar 1 Section 3 is PCC surface with joint seal damage, joint spalling, and LTD cracking documented in 2017. The PCI value of this airfield pavement was 84. T-hangar 2 has two sections: Section 1 and Section 2. T-hangar 2 Section 2 is an AC pavement with alligator cracking, block cracking, depression, L&T cracking, patching, raveling, rutting, swelling, and weathering pavement distresses with a PCI value of 15.

From the experience of sUAS data collection in the airport, it has been observed that it is challenging to collect sUAS data efficiently. Thus, the decision has been made to collect sUAS data on a priority basis.

Table K-1. Priority Level of the sUAS Data Collection (Iowa DOT, 2018)

Priority level	Branch ID	Section ID	Surface Type	2019 PCI	Type of Distresses	Area (m <sup>2</sup> )
1	R15BO	2	PCC	76	ASR, corner spalling, joint seal damage, joint spalling, large patch, LTD cracking, popouts, small patch	1329.5
2	R15BO	1	PCC	95	Corner spalling, joint seal damage	20917.3
3	T01BO	1-6	PCC	89-97	ASR, corner spalling, joint seal damage, joint spalling, LTD cracking, shrinkage cracking	21157.3
4	TH02BO	2	AC	15	Alligator cracking, block cracking, depression, L&T cracking, patching, raveling, rutting, swelling, weathering	2227.3
5	TH01BO	1 and 2	AC	70, 63	Alligator cracking, L&T cracking, raveling, swelling, weathering	858.9
6	TH01BO	3	PCC	84	Joint seal damage, joint spalling, LTD cracking	2258.2

AC = Asphalt concrete pavement

PCC = Portland cement concrete pavement

L&T cracking = Longitudinal and transverse cracking

LTD cracking = Longitudinal, transverse, and diagonal cracking

The focus will also be on high-resolution red, green, blue (RGB) optical and thermal data collection from three sample units located on Runway 15/33 Section 2 (Figure K-3). The sample units are 15/33 Section 2 Sample Unit 1, 3, and 7. The first two sample units are located very close to each other.

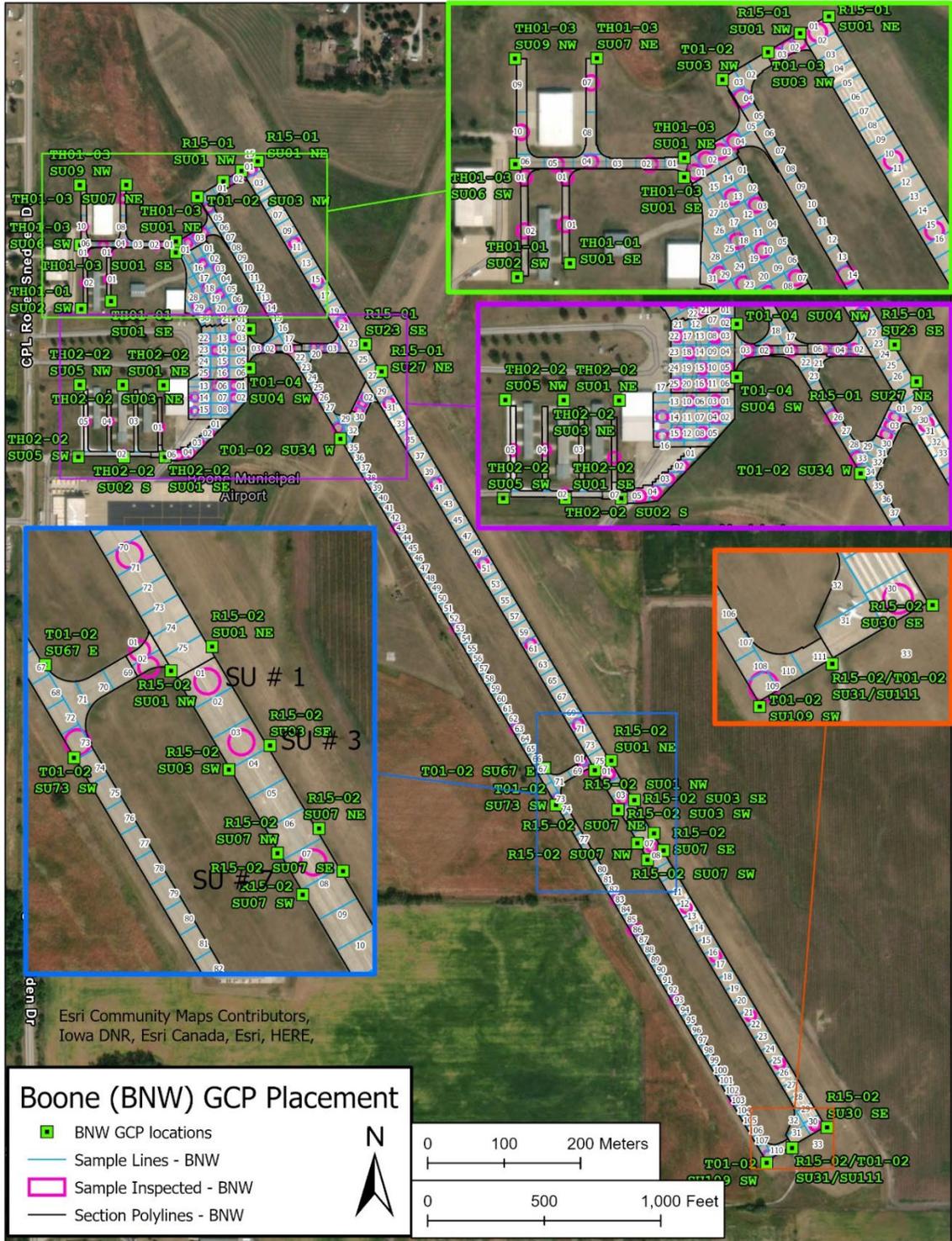


Figure K-1. Recommended Locations for GCPs

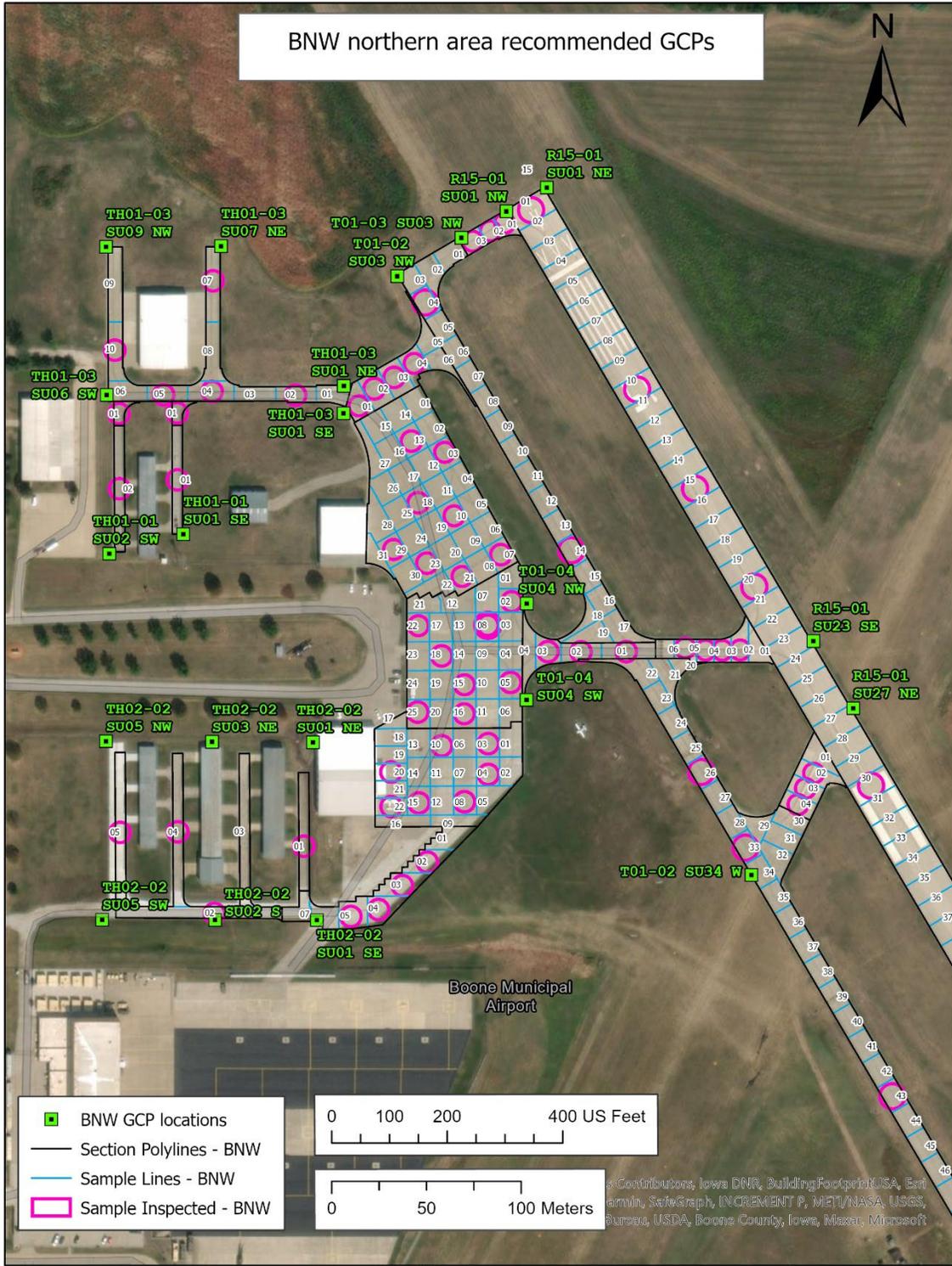


Figure K-2. Recommended Locations for GCPs at the Northern End



Figure K-3. Recommended Locations for GCPs at the Central Section of the Airport

## K.5 OBJECTIVES FOR UPCOMING JUNE 2021 UAS DATA COLLECTION

### K.5.1 Mavic 2 Pro

Optical imagery is planned to be collected at 15.2 m above ground level (AGL) with Mavic 2 Pro 20 mp for the complete Runway 15/33 and Taxiway 01. MTRI is planning to bring 2 Mavic 2 pro sUASs with additional batteries to collect the following data. At least three preplanned flights are likely to be needed to cover the runway and taxiway.

The flight plans for these missions are created with the Pix4D Capture Android application, which has been successfully used in mission planning for previous research data. An 80% forward overlap and a 70% side overlap will be used, standard for most missions where close-range photogrammetry software is used to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully for creating outputs for different flights at Custer Airport (TTF), Monroe, Michigan and Grosse Ile Municipal Airport (ONZ), Grosse Ile Township, Michigan, and Coles County Memorial Airport (MTO), Coles County, Illinois. Figures K-4 and K-5 show drafts of the preplanned mission for a runway mission at 15.24 m based on using the Mavic 2 Pro sUAS.

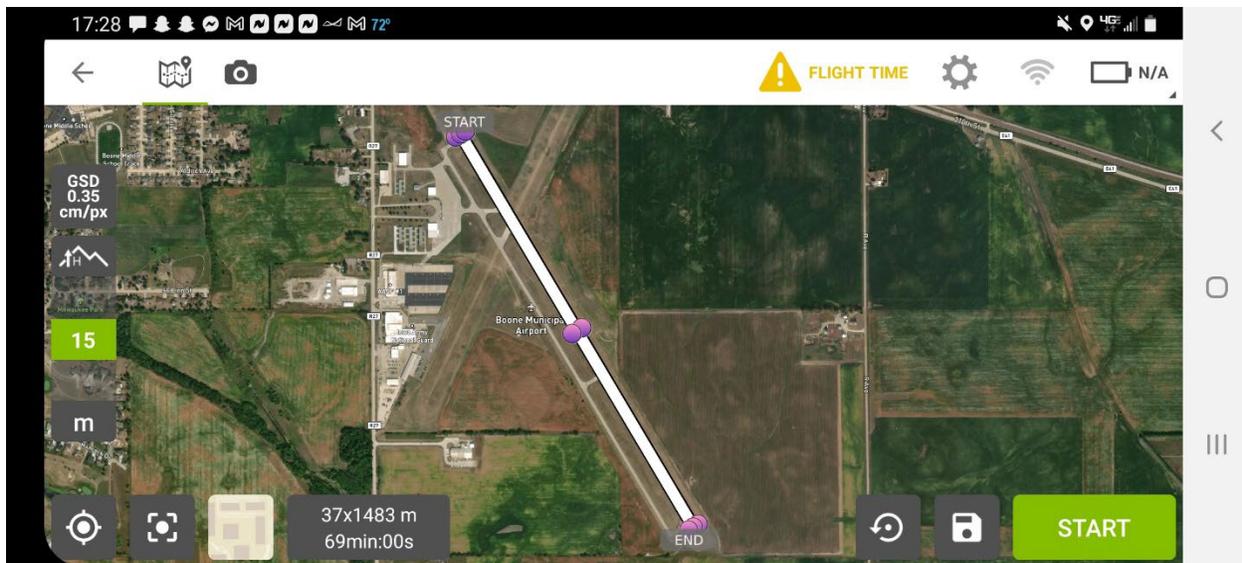


Figure K-4. Mavic 2 Pro Flight Plan for Runway 15/33

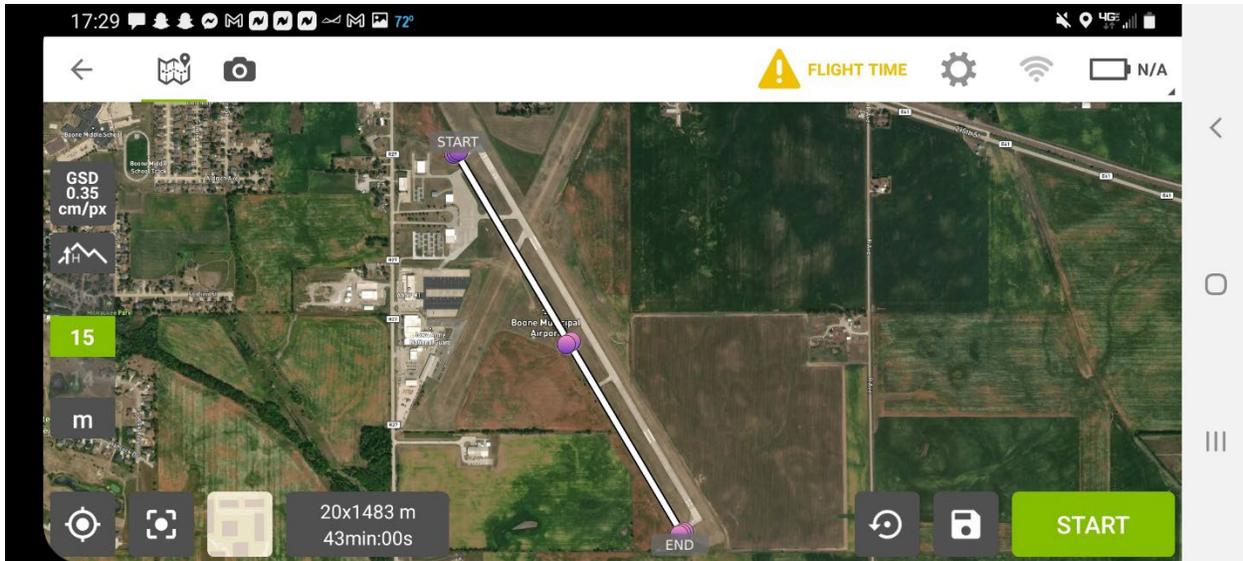


Figure K-5. Mavic 2 Pro Flight Plan for Taxiway 1

### K.5.2 Mavic 2 Enterprise Advanced

Optical and thermal imageries will be collected over the sample units using Mavic 2 Enterprise Advanced (M2EA). Four preplanned flights will be required to collect this data. Two M2EA units will be available, one with seven batteries and one with six batteries. Batteries can be recharged during the day with an available generator. The average flight time is estimated at 20 minutes per battery. The optical RGB data will be collected from 15.2 m AGL and stereo thermal data from 24.4 m AGL. The preplanned flights are shown in Figures K-6 and K-7.

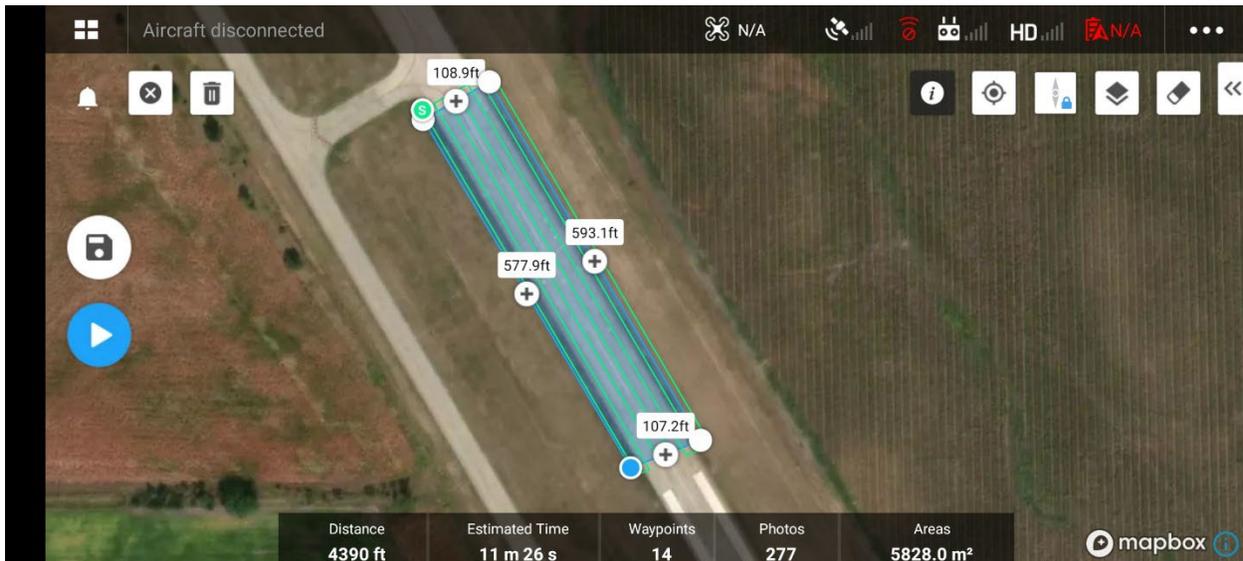


Figure K-6. Flight Plan for Optical RGB Data Collection with M2EA Over Three High-Resolution Sample Units

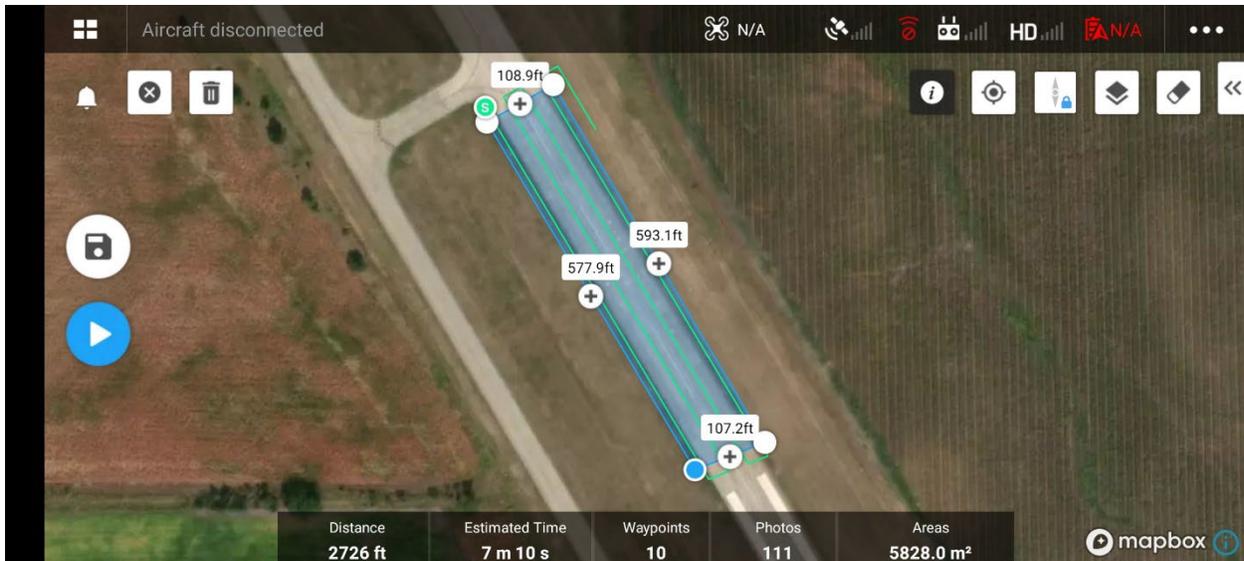


Figure K-7. Flight Plan for Stereo Thermal Data Collection with M2EA Over Three High-Resolution Sample Units

In addition to the sample units, optical RGB and thermal data of the T-hangers will also be collected using the M2EA. At least three preplanned missions will be required for each type of data collection.

### K.5.3 Bergen Hexacopter or Tarot X6 V2.2

With its high-resolution sensors, the Bergen Hexacopter has been the main high-resolution sUAS platform used to collect sUAS data for the last several years. This platform has been successfully deployed in optical RGB, thermal, and multispectral sensors in Grosse Ile Municipal Airport (ONZ), Grosse Ile Township, Michigan; Custer Airport (TTF), Monroe, Michigan; and Coles County Airport (MTO), Coles County, Illinois. The Bergen Hexacopter will be flown manually to collect optical imagery at 18.3 m from the selected sample units of the runway and T-hangar. The team will focus on collecting optical RGB data using a Nikon D850 45.7-mp camera.

Because of the closeness of the two selected sample units on Runway 15/33 Section 2, they will be covered in one manual flight. An attempt will be made to collect the T-hangar 2 Section 2 data with two more manual flights. Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired sample units are. At 60 feet, the RGB optical imagery will be 1.5-mm (0.06 in.) resolution. Manual control is planned because the areas planned for data collection are small, and the older Bergen flight-control hardware and software are not compatible with current mission planning applications. The maximum speed of the platform during data collection will be 2 m/sec.

The Tarot X6 V2.2 sUAS platform was recently purchased with a real-time kinematic (RTK) unit to accurately collect sUAS data. This sUAS platform comes with a PixHawk flight controller and allows users to preplan the sUAS flight. An attempt will be made to mount the Nikon D850 45.7-mp camera on Tarot X6 platform to be flown at 18.3 m to collect RGB data with a resolution of

1.5 mm/pix. Only one sUAS platform between Bergen Hexacopter and Tarot X6 V2.2 will be flown to collect the high-resolution RGB data.

#### K.5.4 mdMapper-1000+

The team also has a German-made mdMapper-1000+ UAS that is focused on photogrammetric optical data collection. The mdMapper-1000 was purchased in 2020 to detect map defects and measure 3D rates of construction progress. This system has been flown at 18.3 m and 30.5 m AGL with lesser winds and turbulence at TTF, Monroe, Michigan and MTO, Coles County, Illinois. The mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 100 feet, the optical imagery will have a 5-mm resolution. The preplanned mission has been shown below in Figure K-8. Details of all planned data collection flights for all sUAS are provided in Table K-2.

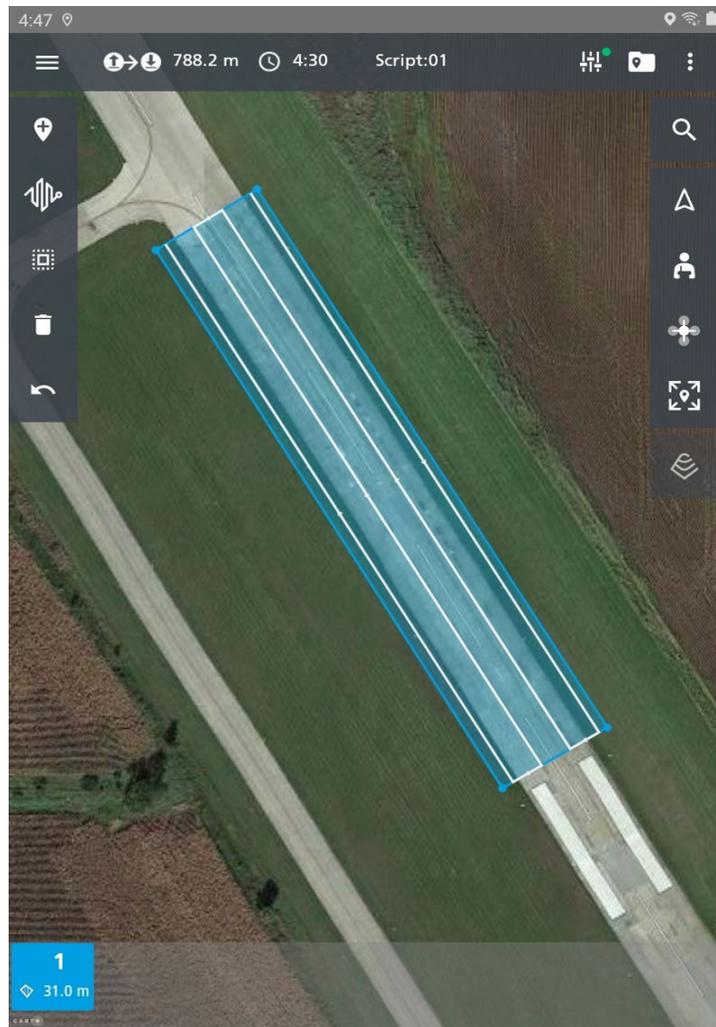


Figure K-8. Flight Plan for RGB Optical Data Collection with mdMapper1000+ Over 3 High-Resolution Sample Units

Table K-2. Planned Sensors and Flying Heights for All sUAS

Date	Target Area	sUAS Platform	Sensors	AGL m	Approximate Resolution mm/pix
6/29 and 6/30	Runway 15/33 Section 2 Sample Unit 1, 3, and 7	Bergen Hexacopter or Tarot X6	45.7-mp optical RGB Nikon D850	18.3	1.5
		M2EA	48-mp optical RGB	15.2	2.5
		M2EA	512 x 640 thermal	24.4	3.1
		mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	30.5	5
6/29	Runway 15/33	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
6/29	Taxiway 1	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
6/29	T-hangar 2 Section 2 and T-hangar 1 Section 1, 2, and 3	M2EA	48-mp optical RGB	15.2	2.5
		M2EA	512 x 640 thermal	24.4	3.1

Mavic 2 Enterprise sensor is not a true 48 mp.

#### K.6 PILOTS AND SUPPORT TEAM

The research team has four research staff available to fly the sUAS, all of whom have a current Part 107 Unmanned Pilot’s Certificate. Other crew members are available to help with GCP GPS data collection and capturing pavement distress images. Standard procedure is to have at least two staff members for each UAS flight: one UAS pilot and one safety observer. In simultaneous data collection, each sUAS pilot will have a dedicated field observer.

*Provisional timeline for data collection day – All timing is subject to change based on weather conditions and airport operations.*

A part of the research team will travel to Ames, Iowa, from Michigan on June 28, 2021. The full team will travel to BNW on June 29, 2021. A safety briefing will be conducted by the pilot-in-command before entering the airfield pavement. Two members of the research team will place the AeroPoints throughout the airport as outlined in the GCP placement map. After placing the GCPs, the research team will focus on collecting thermal and optical of the airfield pavement on a priority basis, as shown in Table K-1. If time allows, the data collection will be concluded on the same day. Otherwise, the remaining data will be collected on June 30, 2021. Downtime will accommodate battery/sensor swaps and remain grounded while aircraft operate in the vicinity.

The data-collection team will have their aviation radio on at all times for data collections on Unicom frequency 123.0 used for BNW. Communications via the radio should be in the form of “Boone. [Announcement]. Boone” as done in previous UAS data collection.

Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities such as data-collection conversations, battery charging, and

checking data collection outside the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends is being used, so the team will stay outside these areas when not completing a data collection. The team will keep away 76.2 m horizontally from any moving aircraft and will not operate UAS if wind gusts exceed 24.1 kph and temperature above. A hand-held anemometer will be used to measure wind speed before each mission.

#### K.6.1 Planned Data Collection Timeline

The research team will try to collect as much data as possible on June 29, 2021. However, as shown in Figure K-7, rain is expected on June 29, 2021, which could pose an extra challenge in the scheduled data collection. Therefore, if a significant amount of data is not collected on June 29, 2021, the remaining data will be collected on June 30, 2021. If required, the data-collection team will be at BNW till 5:00 PM on June 30, 2021.

#### **June 29, 2021**

8:00 a.m. – 8:30 a.m.: AeroPoints placement based on the ground control placement map.

8:30 a.m. – 5:00 p.m.:

- Mavic 2 Pro data collection
  - Runway 15/33 Section 2 is 4,808 ft x 75 ft or 1,465 m x 22.9 m
    - Estimated flight time to only collect imagery: 1.2 hours
    - Estimated total time to collect full runway: 1.8 hours (4 flights)
  - Complete Taxiway 1 is 4,808 ft x 35 ft
    - Estimated flight time to only collect imagery: 0.7 hour
    - Estimated total time to collect full runway: 1.2 hour (3 flights)
- Mavic 2 Enterprise Advanced.
  - Runway 15/33 Section 2 Sample Unit 1 and 3 - 180 ft x 75 ft, Runway 15/33 Section 2 Sample Unit 7 - 60 ft x 75 ft (Optical RGB)
    - Estimated Flight Time to only collect imagery: 12 mins
  - Runway 15/33 Section 2 Sample Unit 1 and 3 - 180 ft x 75 ft, Runway 15/33 Section 2 Sample Unit 7 - 60 ft x 75 ft (thermal)
    - Estimated Flight Time to only collect imagery: 7 mins
  - T-hangar 2 Section 2 (Optical RGB)
    - Estimated Flight Time to only collect imagery: 20 mins
  - T-hangar 2 Section 2 (thermal)
    - Estimated Flight Time to only collect imagery: 14 mins
  - T-hangar 1 Section 1, 2, and 3 (Optical RGB)
    - Estimated Flight Time to only collect imagery: 15 mins
  - T-hangar 1 Section 1, 2, and 3 (thermal)
    - Estimated Flight Time to only collect imagery: 10 mins

5:00 p.m. – 5:30 p.m.: GCP collection and data-collection conclusions.

**June 30, 2021 (If required)**

8:30 a.m. – 9:00 a.m.: AeroPoints placement based on the ground control placement map

9:00 AM – 11:30 PM: Remained data collection

- Bergen Hexacopter or Tarot X6 with Nikon D850
  - Runway 15/33 Section 2 Sample Unit 1 and 3 - 180 ft x 75 ft
    - Estimated Flight Time to only collect imagery: 2 mins
  - Runway 15/33 Section 2 Sample Unit 7 - 60 ft x 75 ft
    - Estimated Flight Time to only collect imagery: 1 mins
- Microdrones md4-1000+
  - Runway 15/33 Section 2, Subunits 1, 3, and 7 - 590 ft x 75 ft
    - Estimated Flight Time to only collect imagery: 4:30 minutes

11:30 p.m. – 12:00 p.m.: AeroPoints collection and data collection conclusion

The data-collection schedule is developed based on the weather condition shown in the forecast (Figure K-7). There might be thunderstorms on both days, but the skies are expected to be clear by the later part of the day.

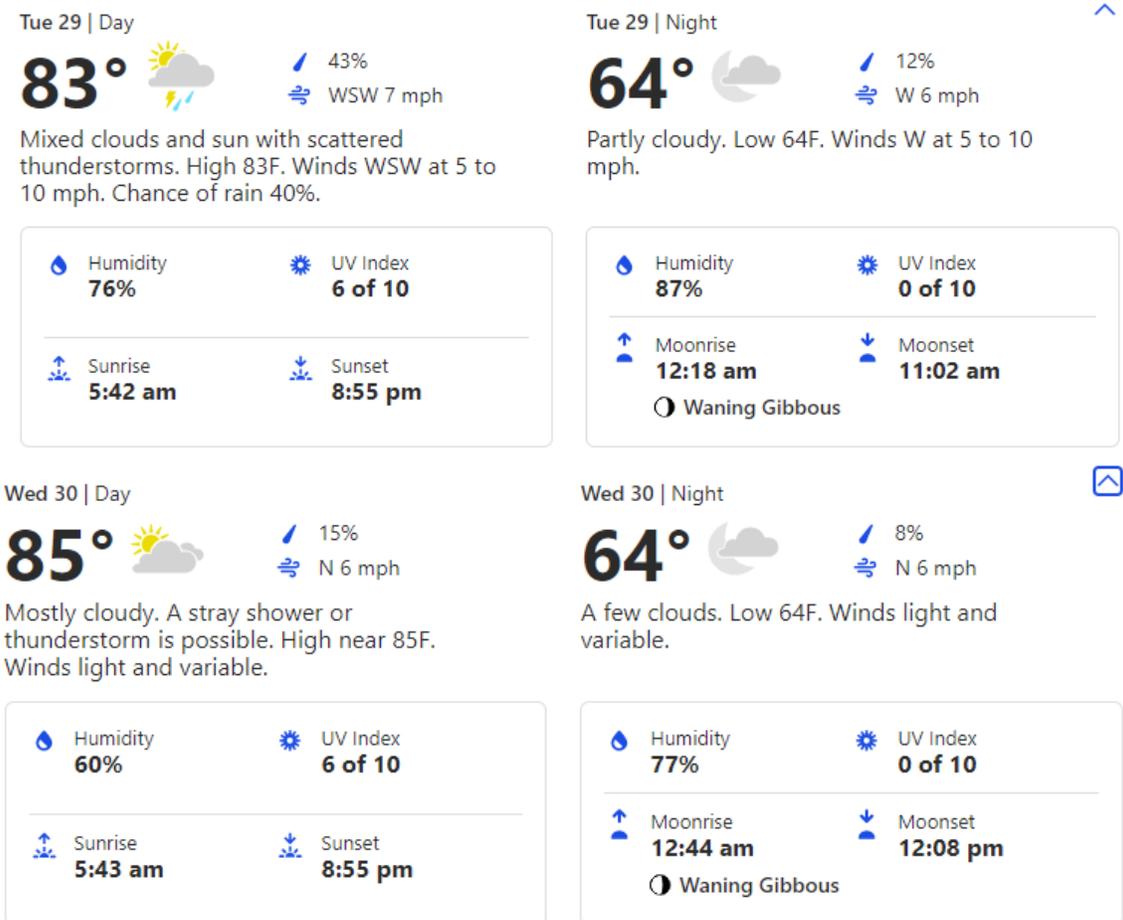


Figure K-7. Weather Forecast for Boone, Iowa for June 29 and June 30, 2021

All missions will be documented by a photographer designated for each mission. One crew member is not flying the UAS or acting as an observer (this is usually one of the GCP data-collection crew members).

A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date if any final modifications are needed.

#### K.7 REFERENCES

Iowa DOT. (2018). *Boone Municipal Airport Pavement Management Report*.  
<https://iowadot.gov/aviation/pavementmanagement/airport-details/docs/reports/boone-report-2020.pdf>

## APPENDIX L—AIRPORT CONDITION SURVEY SAFETY PLAN FOR BOONE MUNICIPAL AIRPORT, BOONE, IOWA IN JUNE 2021

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Boone Municipal Airport (BNW) in Boone, Iowa. This document was developed along with the data collection plan provided in Appendix K. Figures L-1 to L-3 show the travel plans for the research team, and Figures L-4 and L-5 highlight BNW layout.

Data collection: June 29 and 30, 2021

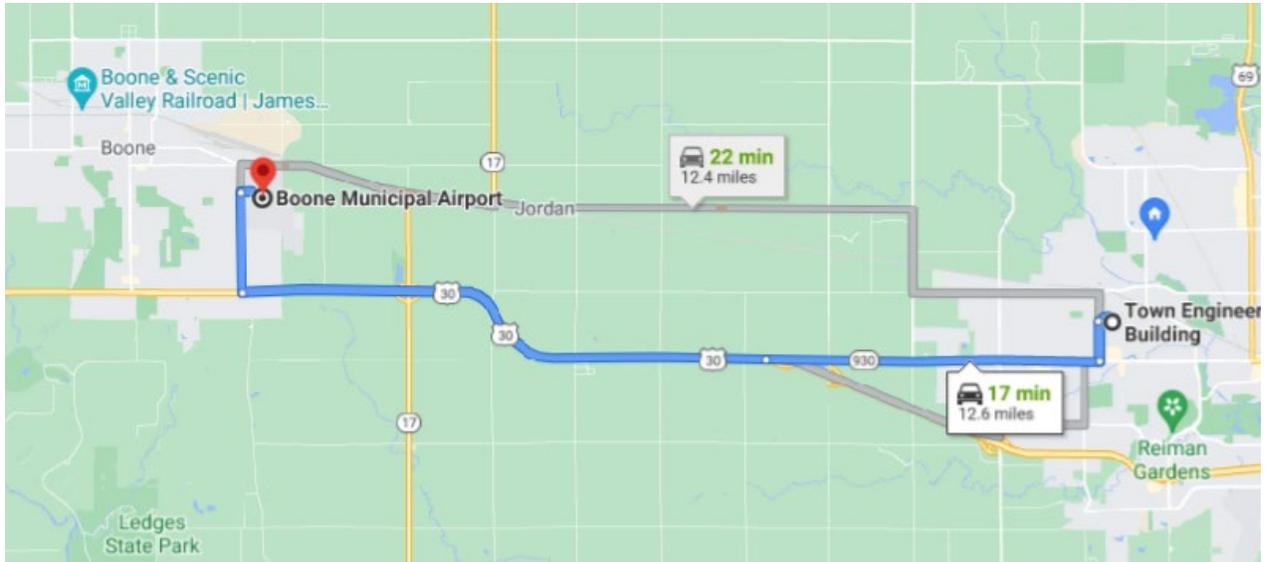


Figure L-1. Travel Route from Ames, Iowa to Boone Municipal Airport, Boone, Iowa

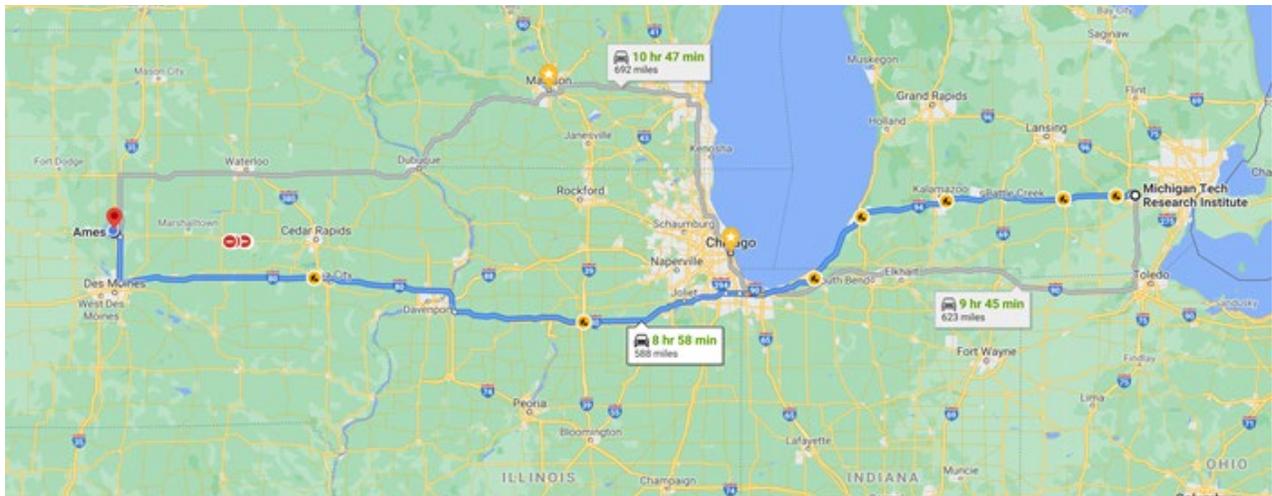


Figure L-2. Travel Route from Ann Arbor, Michigan to Ames, Iowa

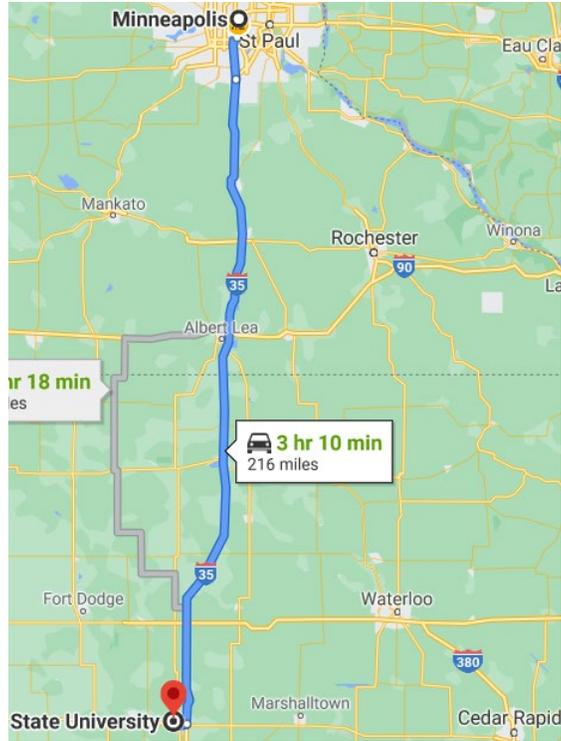


Figure L-3. Travel Route From Minneapolis, Minnesota to Ames, Iowa

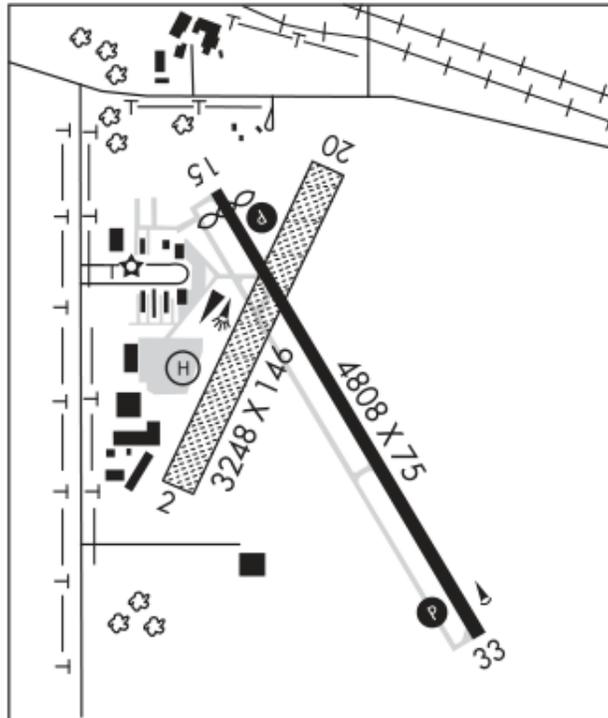


Figure L-4. Airport Diagram of BNU in Boone, Iowa

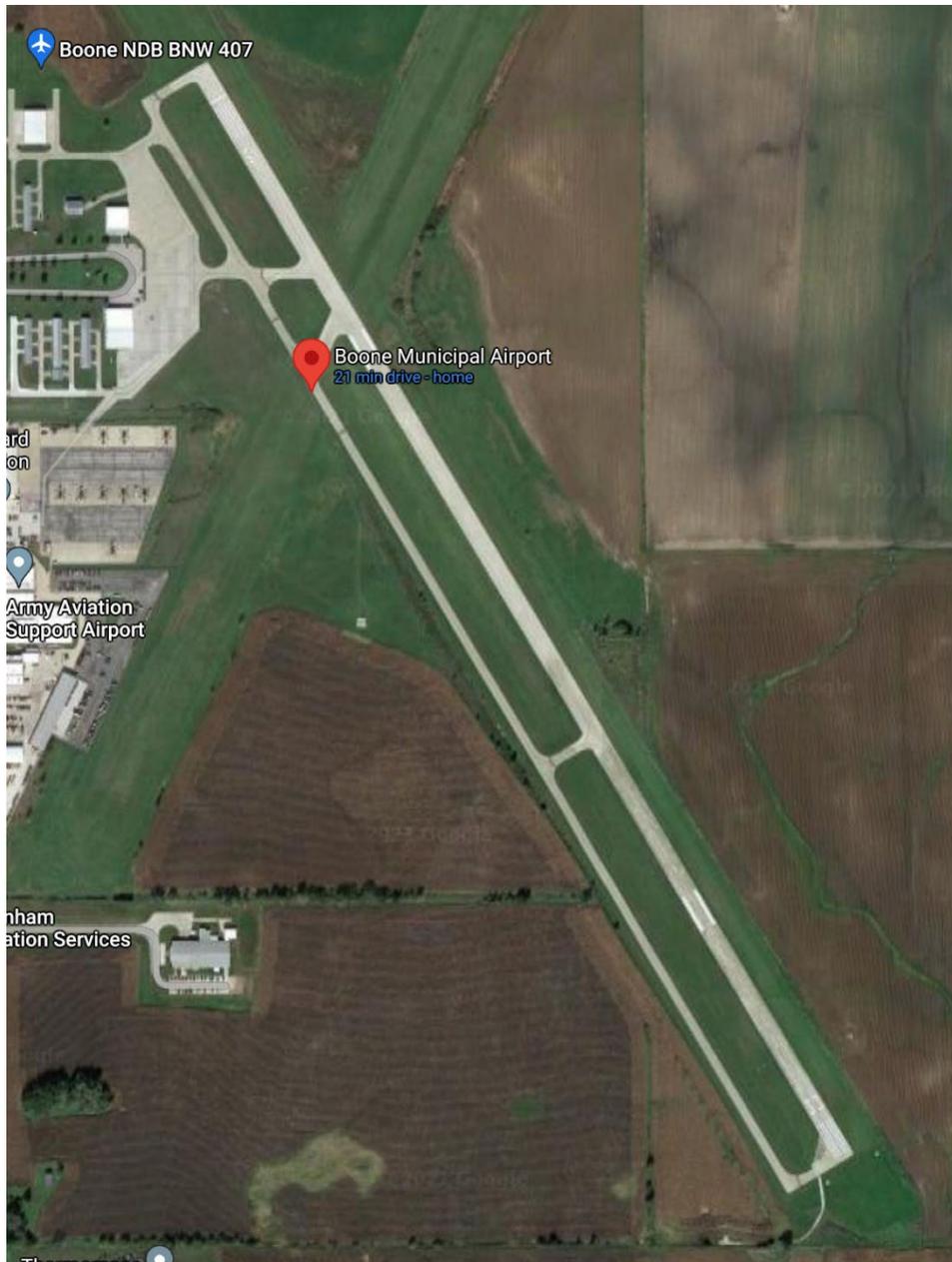


Figure L-5. View of BNW in Boone, Iowa

## L.1 SAFETY INFORMATION

For any safety questions during field data collection, please contact:

- Halil Ceylan, Iowa State University (ISU) (Project Principal Investigator and Lead)
- Colin Brooks, Michigan Tech Research Institute (MTRI) (Project Lead) (Also a backup pilot, ground control collector)
- Richard Dobson (Lead Pilot-in-command)

Other participants are:

- Matthew T. Brynick, Federal Aviation Administration (FAA) (Civil Engineer, Airport Technology Research & Development, FAA)
- Abdullah Sourav, ISU (drone pilot)
- Chris Cook, MTRI (road & drone safety observer, backup pilot)
- Julie Carter, MTRI (ground control data collector, backup road & drone safety observer)
- Olivia Brouillette, ISU (undergraduate research assistant intern)
- Robin Valle, California State University, (undergraduate research assistant intern)

Proposed schedule:

- MTRI team will depart MTRI at 1 p.m. on June 28, arriving in Ames, Iowa approximately 11:30 p.m. local time (travel time to Ames, Iowa from MTRI is approximately 9 hours minus the time change to Central time).
- Olivia Brouillette will depart from Minneapolis, Minnesota at 7 a.m. on June 28, arriving in Ames, Iowa approximately 10 a.m. (travel time is approximately 4 hours).
- Robin Valle will depart from Los Angeles, CA on June 27, arriving in Ames, Iowa approximately 10 p.m. the same day.
- On June 29, the ISU and MTRI team will depart Ames, Iowa at 7:30 a.m., arriving in Boone, Iowa approximately 8 a.m. local time (travel time to BNW from Ames is approximately 20 minutes). Will survey the airport on June 29, 2021 and return to Ames after leaving Boone at 5 p.m.
- On June 30, 2021, the ISU and MTRI team will depart Ames, Iowa at 8:00 a.m., arriving in Boone, Iowa approximately 8:30 a.m. local time (travel time to BNW from Ames is approximately 20 minutes). Will survey the airport on June 30, 2021, if required, and leave before 5 p.m.
- MTRI team will leave Ames on July 1, 2021.

## L.2 FIELD SITE

BNW at Boone, Iowa is the field site for data collection. The BNW airport manager is Dale Farnham ([defarnham@msn.com](mailto:defarnham@msn.com)), who has agreed to sUAS field deployment. The general phone number for the airport is (515) 291-5094.

## L.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on a reflective vest, safety glasses, and appropriate clothing. Driving vehicles must have yellow caution lights present.

- A stand-up safety briefing will be held at the beginning of any data-collections days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (high-visibility vest and glasses) at all times.

- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic and ensuring the pilot's safety . The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- The team will operate on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway, or a taxiway is being surveyed by sUAS, operations (land sUAS) will cease and then continue after the manned aircraft have finished their takeoff or landing procedures.
- The data-collection team will have two sUAS data-collection teams, with Richard Dobson (MTRI) and Abdullah Sourav (ISU) as the lead pilots for each team. Each team will have their own Sporty's® 400/ YEASU Spirit aviation radio, which will be on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 123.0 used for BNW.
- AeroPoint™ GCPs will be put down at the beginning of each day of data collection, with Julie Carter and Colin Brooks taking care of this.
- Windows of moving vehicles will be kept open, with vehicle radios off, to enable listening for unexpected aircraft when driving on runways and taxiways.
- Crew members should always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members should stand on airfield pavement during data collections only if needed.
- Crew members should not stand in open traffic lanes at the airport. If walking along an open stretch of roadway, walk against the flow.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data collection conversations, battery charging, and checking data collection, outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 m from the runway centerline and 304.8 m from the ends of the runway is being used, so team will stay outside these areas when not completing data collection. The team will keep 76.2 m horizontally away from any moving aircraft.

#### L.4 SMALL UNMANNED AIRCRAFT SYSTEM SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants a day prior to field collections of where the sUAS will be operating, safe places and minimum distance to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a remote pilot's certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly.

- Remain a safe distance from and do not stand directly below a flying sUAS.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are being operated unless it is an immediate emergency.
- All sUAS operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until safe passage of the manned aircraft.
- Always listen to the pilot-in-command.

- The field team will have a small fire extinguisher on hand at the place of sUAS operation in case of a battery fire.

## L.5 FIRST AID AND MEDICAL

- First aid kit will be on site with the field crew for all site visits.
- Emergency number is 911.
- Nearest hospital location to study site: Boone County Hospital, Boone, Iowa 50036 (2.4 km, 5 minutes).
  - 1015 Union St, Boone, Iowa 50036. Phone: (515) 291-5094 (non-emergency).
- ISU phone number: (515)-294-8213, Paul Kremer (Manager Research, CCEE, ISU). Any workplace injury must be reported to Mr. Kremer if medical care is sought due to any workplace injuries.
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead). Any workplace injury must be reported to Lisa, and appropriate forms filled out if medical care is sought due to any workplace injuries.

## L.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

**Notes:** Most states have lifted COVID-19 restrictions. More information on Iowa COVID-19 guidance is available at: <https://coronavirus.iowa.gov/> and <https://coronavirus.iowa.gov/pages/guidance>.

### L.6.1 ISU'S Covid-19 Safety Plan

- The COVID-19 guidelines were updated for regent institutions in Iowa on May 20, 2021. Mask use continues to be encouraged for those who have not been vaccinated and is optional for those who have been vaccinated.
- Travelers have been encouraged to adhere to Center for Disease Control (CDC) guidance for domestic travel.
- All details are available on the following web addresses provided below:
  - COVID-19 guideline update for regent institutions in Iowa: <https://www.iowaregents.edu/news/board-news/statement-from-president-mike-richards-lifting-regents-state-of-emergency>
  - ISU safety and health policy resources: <https://web.iastate.edu/safety/>
  - ISU safety policy on COVID-19: <https://web.iastate.edu/safety/updates/covid19>
  - ISU gathering and events policy: <https://web.iastate.edu/safety/updates/covid19/events-gatherings>
  - ISU Civil, Construction, and Environmental Engineering (CCEE) safety resources: <https://www.ccee.iastate.edu/safety/>
  - ISU CCEE research and instructional labs and fieldwork safety policies: <https://www.ccee.iastate.edu/files/2019/07/CCEE-Laboratory-Policies-and-Guidelines-CCEE-Safety-and-Health-Committee-and-EHS-Reviewed-and-Approved-2.23.2-3.pdf>

## L.6.2 COVID-19 Safety Plan

MTRI's COVID-19 safety plans have been as follows, which unvaccinated participants are expected to follow closely:

- Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
- Field crew will travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
- Field equipment will be individually assigned as much as possible (for example, whomever starts with a particular sUAS will use that one throughout the day) and will be disinfected with Lysol<sup>®</sup>-type wipes when possible.
- Multiple workers are allowed to travel within the same vehicle when the University's Health & Safety Level is at Level 2.
- As of June 22, 2021, the University is at Level 2. (<https://www.mtu.edu/flex/operations/levels/>) .
- The established cleaning protocol for the MTRI Durango MUST be followed – laminated copies can be found inside the Durango.
- Work is to comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
- COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
- Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
- Research Pandemic Checklist: Research Pandemic Checklist - Google Docs
- Now that the University is back at Level 2, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX M—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN FOR PERRY MUNICIPAL AIRPORT, PERRY, IOWA IN JUNE 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Perry Municipal Airport (PRO) in Perry, Iowa. This document is developed along with the safety plan provided in Appendix N.

Data Collection Date: Thursday, June 30, 2021 (weather permitting)

### M.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with integrated 20-megapixel (mp) camera (both) with spare batteries [charged]
  - Controller [charged]
  - Integrated controller [charged]
  - Spare 4G Pixel™ phone as a backup controller [charged]
- DJI Mavic 2 Enterprise Advanced (M2EA) with integrated dual 48-mp camera and 640 x 512 thermal camera (two systems – one from Michigan Tech Research Institute (MTRI) and one from Iowa State University (ISU))
  - 7 M2EA batteries from MTRI, 6 batteries from ISU [charged]
  - Smart controller for each drone [charged]
- Bergen Hexacopter with spare batteries [charged]
  - Controller [charged]
  - First-person view (FPV) screen [charged]
  - Optical camera (Nikon D850 45.7 mp) [batteries charged]
- Tarot x6 v2.2 with spare batteries [charged]
  - Controller [charged]
  - FPV screen [charged]
- mdMapper-1000+ with spare batteries [charged]
  - Controller [charged]
  - Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]

### M.2 OTHER EQUIPMENT

- Propeller AeroPoint™ electronic Global Positioning System (GPS)-based ground control targets (20)
- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- 2x Portable 1 TB solid-state drive (SSD)
- 256 GB pendrive
- Folding takeoff pad
- Generator and gas can
- Rugged Olympus Tough TG-5® GPS camera (12 mp) - (for geolocated field photos) (2) [charged]
- Sony Alpha camera (16 mp) for field photos (with zoom lens) (1) [charged].

- MTRI flight logging form (at least 2 copies), completed with information for documenting flight details
- Sporty's® SP-400 (2) and Yaesu® FTA 750L (1) aviation radios, tuned to PRO Unicom frequency 122.8 for the entire time the team is onsite at PRO
  - One aviation radio is for each sUAS data collection team, i.e., two radios for two teams. The third radio is provided for the person(s) placing ground control points (GCPs) or moving on the airfield so that they can operate in separate parts of the airport, completing needed tasks more quickly while staying safe and aware of manned and unmanned aircraft operations on or near PRO.
- MTRI anemometer (for wind speed checking)
- MTRI iPad® Mini with GeoPDF airport map that includes recommended ground control point (GCP) locations to assist with placing GCPs
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- High-visibility vests and protective eyewear
- Facemasks (see COVID-19 portion of the safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled water
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed the day prior to travel to Perry, Iowa.

### M.3 AIRPORT CONTACT INFORMATION

The PRO Airport manager is Jonathan Walter (515-465-3970). Dr. Ceylan has sent Mr. Farnham an email regarding sUAS data collection at PRO on June 16, 2021. Mr. Walter welcomed the research team and kept in close contact with Dr. Ceylan via email.

- Airport webpage: <https://www.perryia.org/perry-municipal-airport.html>
- SkyVector webpage about PRO: <https://skyvector.com/airport/PRO/Perry-Municipal-Airport>

### M.4 FOCUS AREAS FOR DATA COLLECTION

Data collection will focus on the complete Runway 14/32, Taxiway 1, and Apron 1 Section 3 at PRO. The runway has two sections with Portland cement concrete (PCC) pavements. The dimensions of the runway are 1219.5 x 22.9 m, with an area of 27,878 square m. According to a

pavement inspection survey conducted by APTech for Iowa Department of Transportation (Iowa DOT) in 2018 for PRO, the Runway 14/32 section 1 had alkali-silica reaction (ASR), corner break, corner spalling, faulting, joint seal damage, joint spalling, large patch, longitudinal, transverse, and diagonal (LTD) cracking, shattered slab, shrinkage cracking, and small patch with a pavement condition index (PCI) value of 45. In addition, the PCC pavement of Runway 14/32 Section 2 contained ASR, corner break, corner spalling, faulting, joint seal damage, joint spalling, large patch, LTD cracking, popouts, shrinkage cracking, and small patch with a PCI value of 39.

Taxiway 1 of PRO has two sections with PCI values of 68 for Section 1 and 100 for Section 2. The notable PCC distresses found on the Taxiway 1 Section 1 were ASR, corner spalling, faulting, joint seal damage, joint spalling, LTD cracking, and shrinkage cracking (Table M-1).

Similar to previous sUAS data collection at previous airports, only specific sections of the airfield pavement on the Apron or the T-hangar are being focused on . At PRO, Apron 1 Section 3 was selected as the focus area, which had ASR, corner break, corner spalling, joint seal damage, joint spalling, LTD cracking, shattered slab, shrinkage cracking, and small patch in 2017 with a PCI value of 36. PRO is a comparatively smaller airport, and data can be collected within a limited period. The details of the focus area are provided in Table M-1.

Table M-1. Data-Collection Focus Areas and Possible Distresses (Iowa DOT, 2018)

Branch ID	Section ID	Surface Type	2019 PCI	Type of Distresses	Area (sq. m)
R14PR	1	PCC	45	ASR, corner break, corner spalling, faulting, joint seal damage, joint spalling, large patch, LTD cracking, shattered slab, shrinkage cracking, and small patch	16,274.3
R14PR	2	PCC	39	ASR, corner break, corner spalling, faulting, joint seal damage, joint spalling, large patch, LTD cracking, pop-outs, shrinkage cracking, and small patch	12,317.9
T01PR	1	PCC	68	ASR, corner spalling, faulting, joint seal damage, joint spalling, LTD cracking, and shrinkage cracking	553.1
T01PR	2	PCC	100	No distresses	568.9
A01PR	3	PCC	36	ASR, corner break, corner spalling, joint seal damage, joint spalling, LTD cracking, shattered slab, shrinkage cracking, and small patch	3,689.1

PCC= Portland cement concrete pavement

ASR= Alkali silica reaction

LTD cracking = Longitudinal, transverse, and diagonal cracking

The focus will also be on high-resolution red, green, blue (RGB) optical and thermal data collection from three sample units located on Runway 14/32 Section 2. The sample units are

Runway 14/32 Section 2 Sample Unit 1, 4, and 8. The recommended ground control points placement locations and location of the sample units are shown in Figures M-1 and M-2.

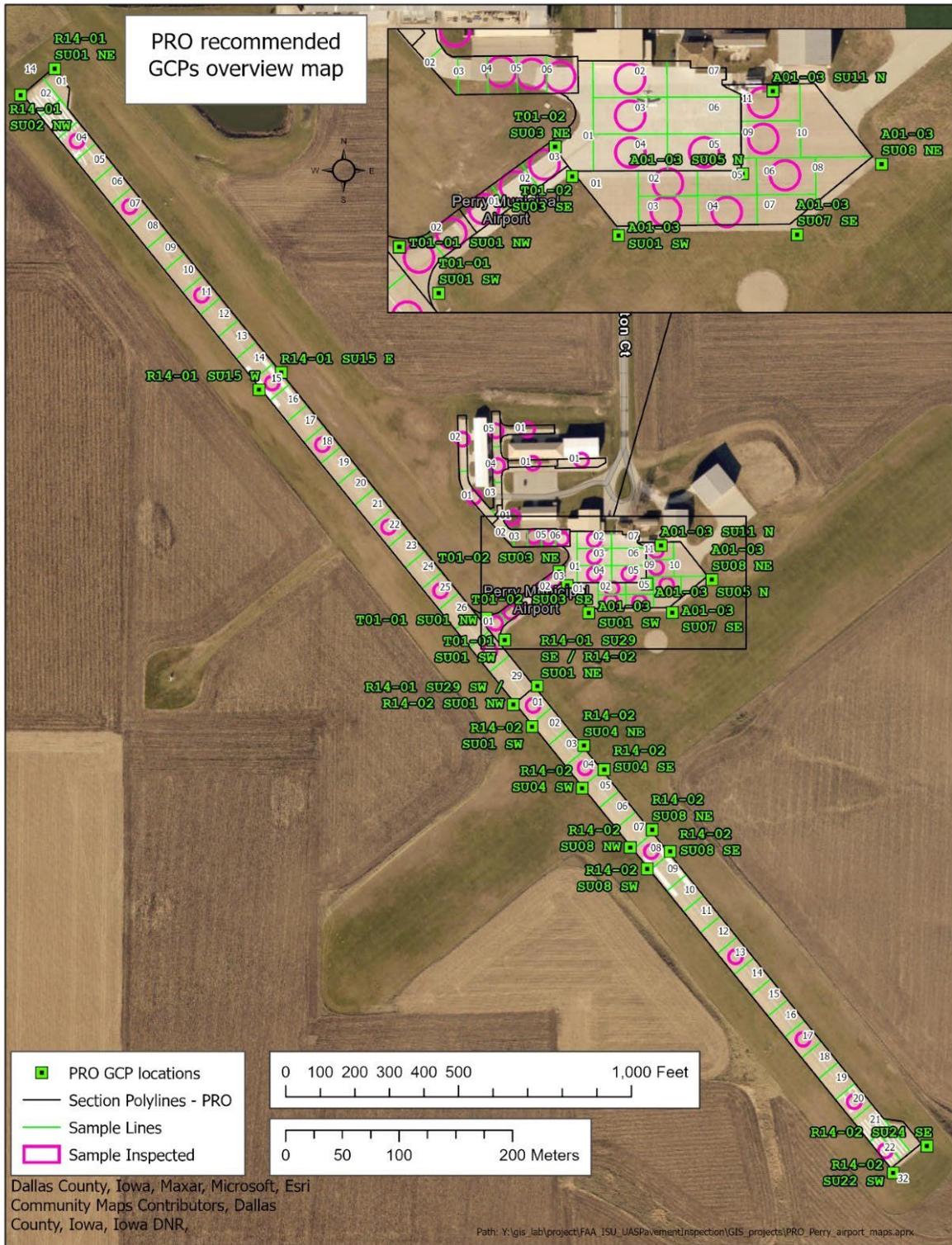


Figure M-1. Recommended Locations for Ground Control Points

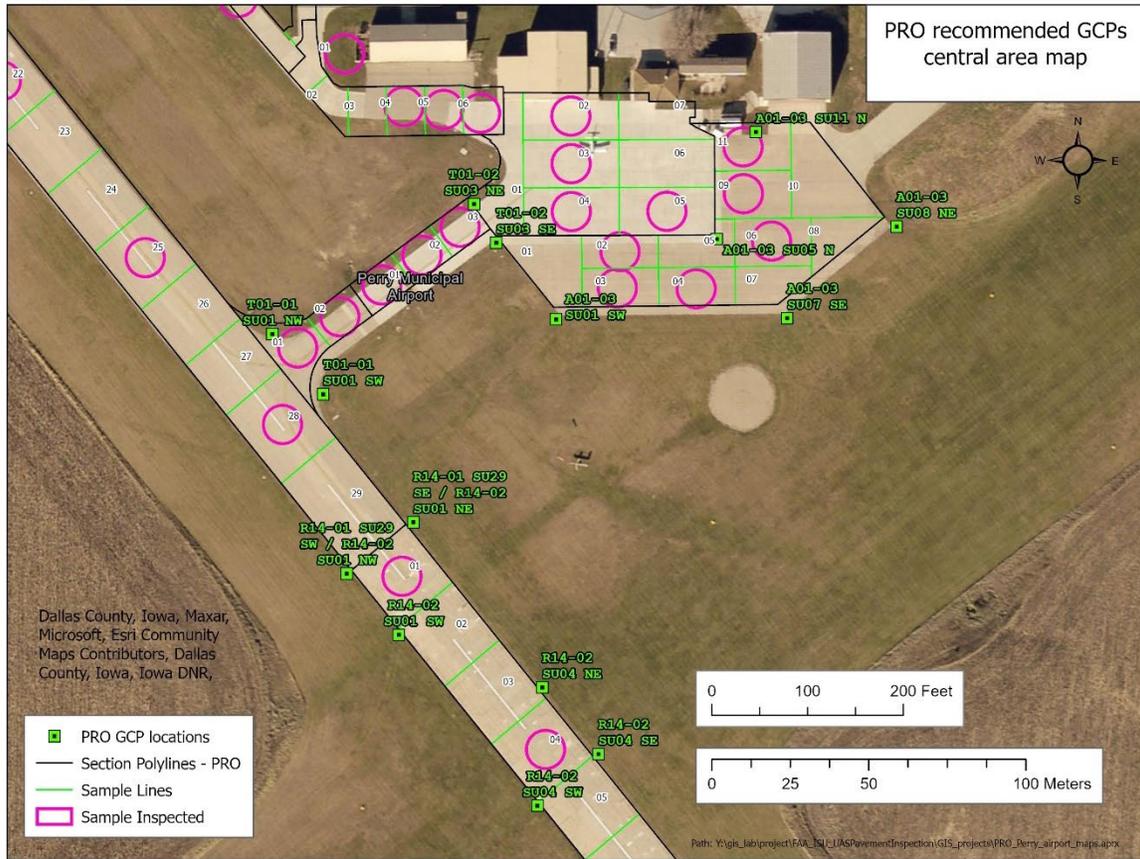


Figure M-2. Recommended Locations for Ground Control Points at the Central Area of the PRO

## M.5 OBJECTIVES FOR UPCOMING JUNE 2021 UAS DATA COLLECTION

### M.5.1 Mavic 2 Pro

Optical imageries will be collected at 15.2 m above ground level (AGL) with Mavic 2 Pro 20 mp for the complete Runway 14/32, Taxiway 1, and Apron 1 Section 3, as shown in Table M-1. MTRI is planning to bring 2 Mavic 2 pro sUAS with additional batteries to collect the following data. At least four preplanned flights are likely needed to cover the focus areas. The details of these flights are also provided in Table M-2.

The flight plans for these missions are created with the Pix4D Capture Android application, which has been successfully used in mission planning for previous research data . An 80% forward overlap and a 70% side overlap standard will be used for most missions where close-range photogrammetry software are used to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully for creating outputs for different flights at Custer Airport (TTF), Monroe, Michigan; Grosse Ile Municipal Airport (ONZ), Grosse Ile Township, Michigan; and Coles County Memorial Airport (MTO), Coles County, Illinois. Figures M-3 and M-4, drafts of the preplanned mission for a runway mission at 15.2 m, are based on using the Mavic 2 Pro sUAS.

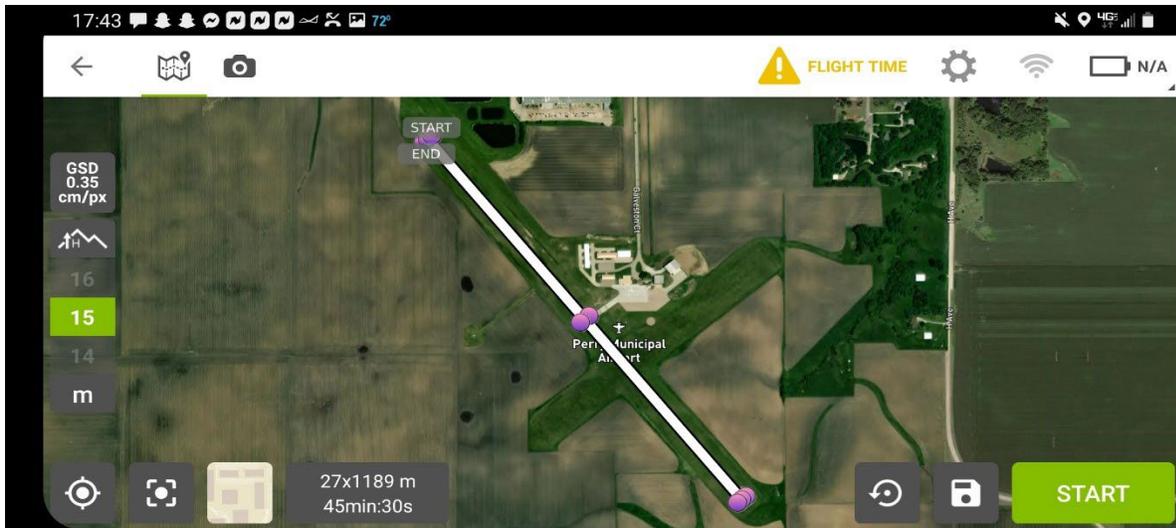


Figure M-3. Mavic 2 Pro Flight Plan for Runway 14/32

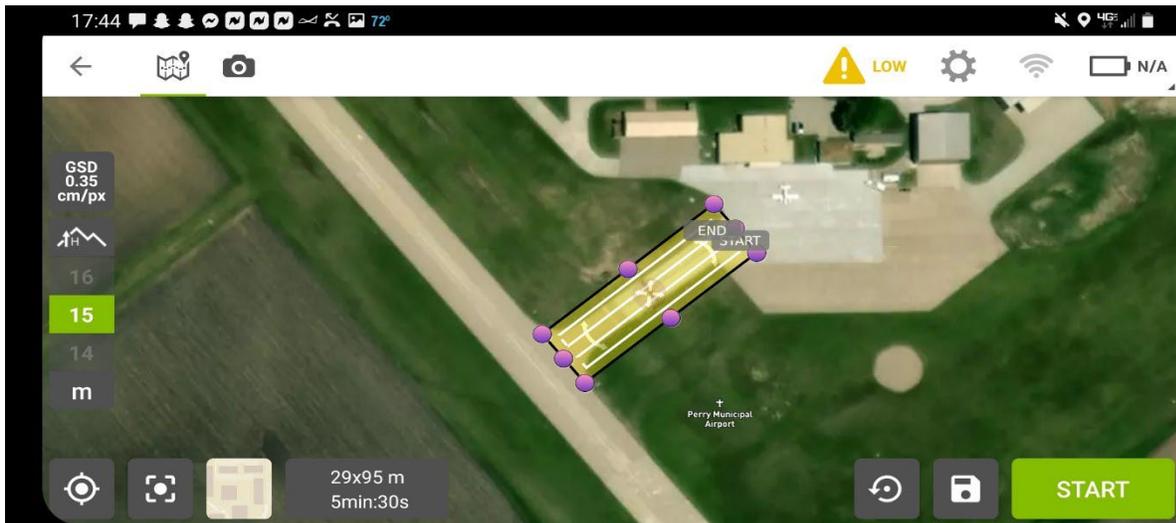


Figure M-4. Mavic 2 Pro Flight Plan for Taxiway 1

### M.5.2 Mavic 2 Enterprise Advanced

Optical and thermal imageries will be collected over the sample units using M2EA combined. Four preplanned flights will be required to collect this data. Two M2EA units will be available, one with seven batteries and one with six. Batteries can be recharged during the day with an available generator. The average flight time is estimated at 20 minutes per battery. The optical RGB data will be collected from 15.2 m AGL and stereo thermal data from 24.4 m AGL. The preplanned flights are shown in Figures M-5 and M-6.

Table M-2. Planned Sensors and Flying Heights for All sUAS

Target Area	sUAS Platform	Sensors	AGL (m)	Approximate Resolution (mm/pix)
Runway 14/32 Section 2 Sample Unit 1, 4, and 8	Bergen Hexacopter or Tarot X6	45.7-mp optical RGB Nikon D850	18.3	1.5
	M2EA	48-mp optical RGB	15.2	2.5
	M2EA	512 x 640 thermal	24.4	3.1
	mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	30.5	5
Runway 14/32	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
Taxiway 1	Mavic 2 Pro	20-mp optical RGB	15.2	3.7
Apron 1 Section 3	M2EA	48-mp optical RGB	15.2	2.5
	M2EA	512 x 640 thermal	24.4	3.1
	Mavic 2 Pro	20-mp optical RGB	15.2	3.7

AGL = Above ground level

\*Mavic 2 Enterprise sensor is not a true 48 mp.

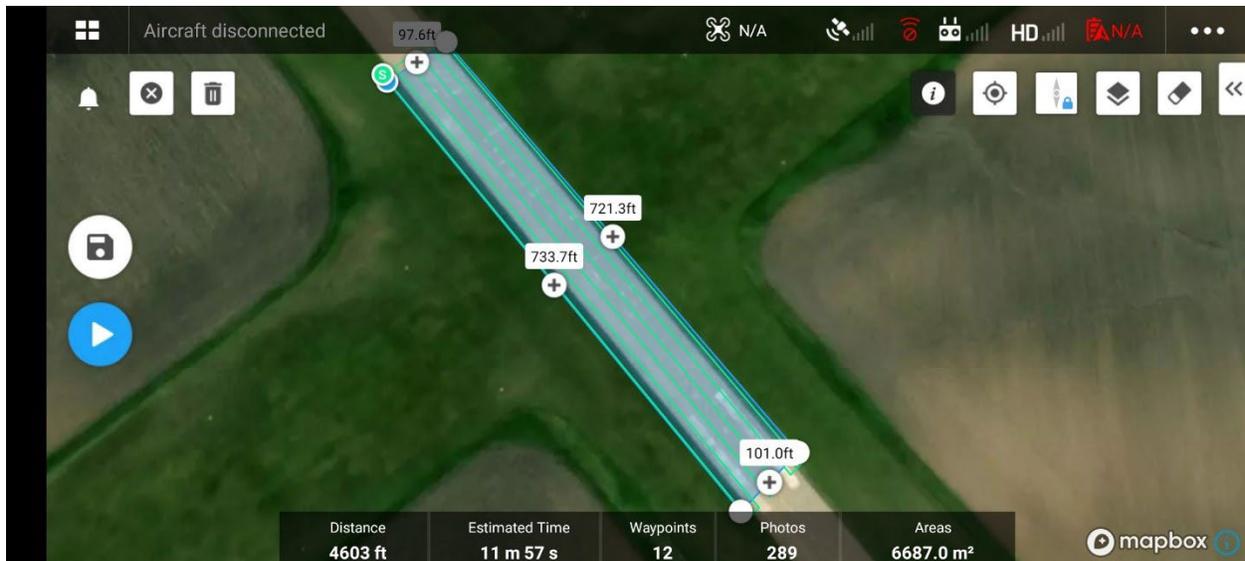


Figure M-5. Flight Plan for Optical RGB Data Collection with M2EA Over Three High-Resolution Sample Units



Figure M-6. Flight Plan for Stereo Thermal Data Collection with M2EA Over Three High-Resolution Sample Units

In addition to the sample units, optical RGB and thermal data of Apron 1 Section 3 will also be collected using the M2EA, as shown in Figures M-7 and M-8.

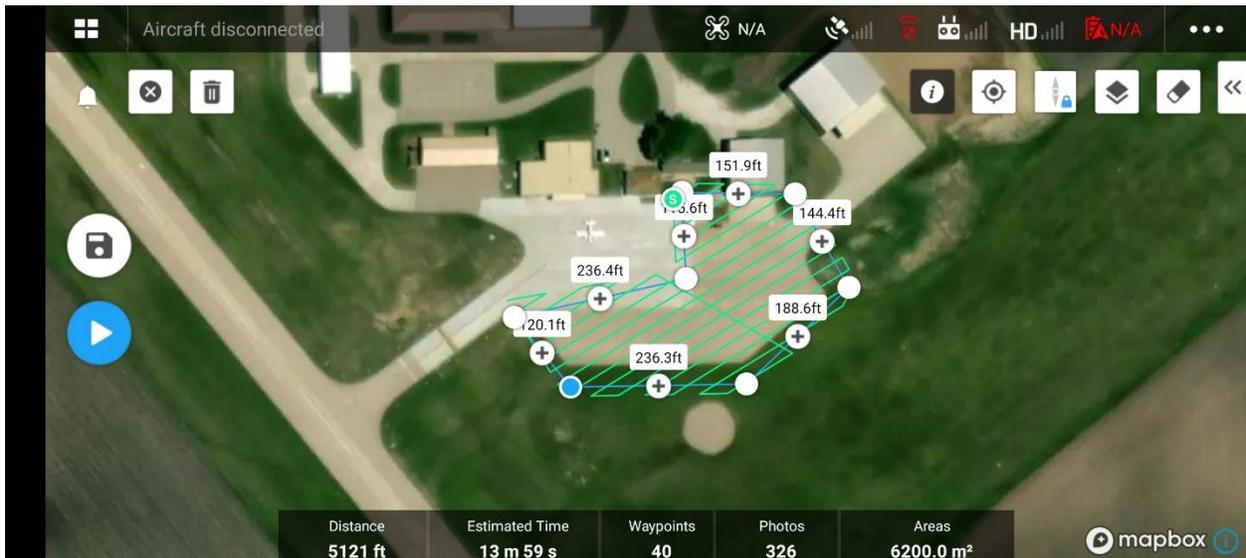


Figure M-7. Flight Plan for RGB Optical Data Collection with M2EA Over Apron 1 Section 3



Figure M-8. Flight Plan for Stereo Thermal Data Collection with M2EA Over Apron 1 Section 3

### M.5.3 Bergen Hexacopter or Tarot X6 V2.2

With its high-resolution sensors, the Bergen Hexacopter has been the main high-resolution sUAS platform to collect sUAS data for the last several years. This platform has been successfully deployed in optical RGB, thermal, and multispectral sensors at ONZin Grosse Ile Township, Michigan; TTF in Monroe, Michigan; MTO in Coles County, Illinois. The Bergen Hexacopter will be flown manually to collect optical imageries at 18.3 m from the selected sample units of the runway and T-hangar. The focus will be on collecting optical RGB data using a Nikon D850 45.7-mp camera.

Because the two selected sample units on Runway 14/32 Section 2 are close, they will be covered in one manual flight. Runway 14/32 Section 2 Sample Unit 8 data will be collected with a second manual flight. Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired sample units are. At 18.3 m, the RGB optical imagery will be 1.49-mm resolution. Manual control is planned because of the small areas planned for data collection and the older Bergen flight control hardware and software not being compatible with current mission-planning apps.

A Tarot X6 V2.2 sUAS platform with real-time kinematic (RTK) unit was recently purchased to accurately collect sUAS data. This sUAS platform comes with a PixHawk flight controller and allows users to preplan the sUAS flight. An attempt will be made to mount the Nikon D850 45.7 mp camera on Tarot X6 platform and fly at 18.3 m to collect RGB data with resolution of 1.5 mm/pix. Only one sUAS platform between Bergen Hexacopter and Tarot X6 V2.2 will be flown to collect the high-resolution RGB data.

#### M.5.4 mdMapper-1000+

The team also has a German-made mdMapper-1000+ UAS to collect photogrammetric optical data. The mdMapper-1000+ was purchased in 2020 to detect map defects on bridge decks and measure 3D rates of construction progress. This system was flown at 18.3 m and 30.5 m AGL with lesser winds and turbulence at TTF and MTO. The mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 30.5-m, the optical imagery will have a 5-mm resolution. The preplanned mission for data collection with mdMapper-1000+ is shown in Figure M-9.

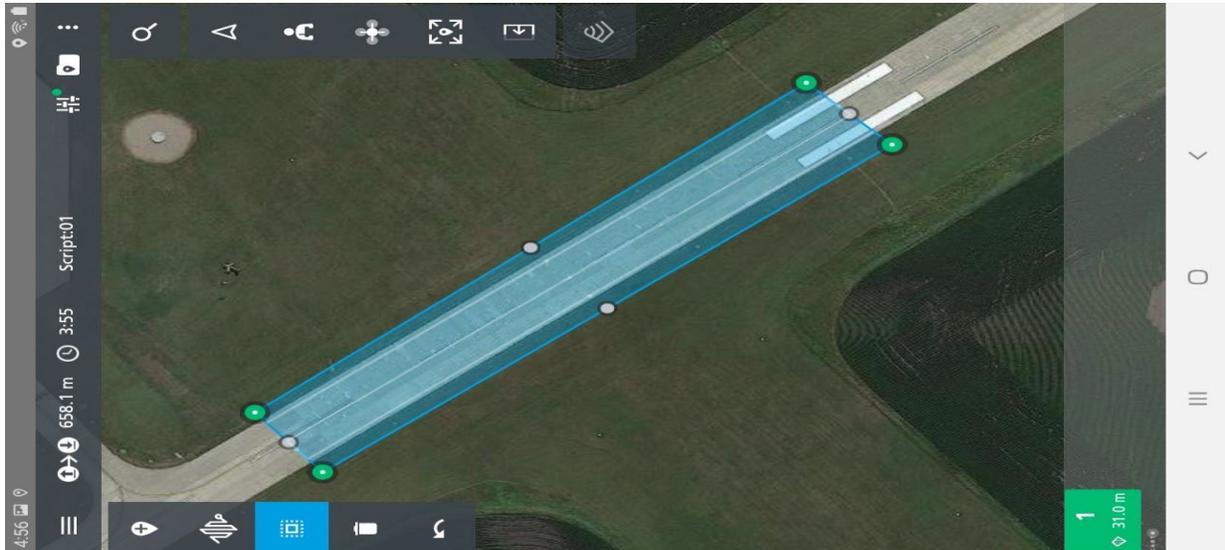


Figure M-9. Flight Plan for RGB Optical Data Collection with mdMapper-1000+ Over Runway 14/32 Section 2 Sample Units 1, 4, 8

#### M.6 PILOTS AND SUPPORT TEAM

The research team has four research staff available for flying the sUAS, all of whom have a current Part 107 Unmanned Pilot's Certificate. Other crew members are available to help with GCP GPS data collection and capturing pavement distress images. The standard procedure is to have at least two staff members for each UAS flight: one UAS pilot and one safety observer. In simultaneous data collection, each sUAS pilot will have a dedicated field observer.

*Provisional timeline for data collection day—All timing is subject to change based on weather conditions and airport operations.*

A part of the research team will travel to Ames, Iowa from Michigan on June 28, 2021. The full team will travel to PRO on June 30, 2021. A safety briefing will be conducted by the pilot in command before entering the airfield pavement. Two members of the research team will place the AeroPoints throughout the airport as outlined in the GCPs map. After placing the GCPs, the research team will focus on collecting thermal and optical images of the airfield pavement in a priority basis, as shown in Table M-1. If time allows, the data collection will be concluded on the

same day. Otherwise, the remaining data will be collected on July 1, 2021. Downtime will accommodate battery/sensor swaps and remain grounded while aircraft operate in the vicinity.

The data-collection team will have their aviation radio on at all times on Unicom frequency 122.8 used for PRO for data collections. Communications via the radio should be in the form of “Perry. [Announcement]. Perry” as done for previous UAS data collection.

Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data collection conversations, battery charging, and checking data collection outside the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway end will be used, and the team will stay outside these areas when not completing a data collection. The team will keep away 76.2 m horizontally from any moving aircraft. They will not operate UAS if wind gusts exceed 24 kmph and temperature above 0 °C. A hand-held anemometer will be used to measure wind speed before each mission.

Below is the planned data-collection timeline:

### **June 30, 2021**

1:30 p.m. – 2:00 a.m.: AeroPoints placement based on the ground control placement map.

2:00 a.m. – 5:00 p.m.:

- Mavic 2 Pro data collection.
  - Runway 14/32 is 1219.5 m x 22.9 m
    - Estimated Flight Time to only collect imagery: 45 mins
    - Estimated Total Time to Collect Full Runway: 78 mins (3 flights)
  - Taxiway 1
    - Estimated Flight Time to only collect imagery: 6 mins
  - Apron 1 Section 3
    - Estimated Flight Time to only collect imagery: 14 mins
- M2EA
  - Runway 14/32 Section 2 Sample Unit 1 and 4 – 73.2 m x 22.9, Runway 14/32 Section 2 Sample Unit 8 – 18.3 m x 22.9 m (Optical RGB)
    - Estimated Flight Time to only collect imagery: 12 mins
  - Runway 14/32 Section 2 Sample Unit 1 and 4 – 73.2 m x 22.9 m, Runway 14/32 Section 2 Sample Unit 8 – 18.3 m x 22.9 (thermal)
    - Estimated Flight Time to only collect imagery: 9 mins
  - Apron 1 Section 3 (Optical RGB)
    - Estimated Flight Time to only collect imagery: 14 mins
  - Apron 1 Section 3 (thermal)
    - Estimated Flight Time to only collect imagery: 11 mins

5:00 p.m. – 5:30 p.m.: GCP collection and data collection conclusions

## July 1, 2021

9:00 a.m. – 9:30 a.m.: AeroPoints placement based on the ground control placement map

9:30 a.m. – 12:00 p.m.: Remained data collection

- Microdrones md4-1000+
  - Runway 14/32 Section 2, Subunits 1, 4, and 8 – 184.1 m x 22.86 m
    - Estimated Flight Time to only collect imagery: 4 mins
- Bergen Hexacopter or Tarot X6 with Nikon D850.
  - Runway 14/32 Section 2, Subunits 1 and 4 – 97.6 m x 22.9 m
    - Estimated Flight Time to only collect imagery: 3.5 mins
  - Runway 14/32 Section 2, Subunits 8 – 24.4 m x 22.9 m
    - Estimated Flight Time to only collect imagery: 1 min

12:00 p.m. – 12:30 p.m.: AeroPoints collection and data collection conclusion

The data collection schedule is developed based on the weather condition shown on the forecast (Figure M-10). There might be a thunderstorm each day, but the skies are expected to be clear by the latter part of the day.

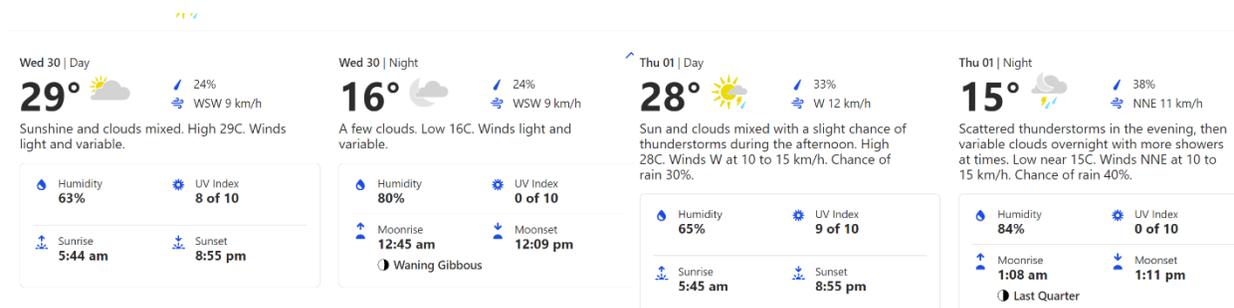


Figure M-10. Weather Forecast for Perry, Iowa

All missions will be documented by a photographer designated for each mission, who is not flying the UAS nor acting as an observer (this is usually one of the GCP data collection crew members).

A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date if any final modifications are needed.

## M.7 REFERENCES

Iowa DOT. (2018). *Perry Municipal Airport Pavement Management Report*.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX N—AIRPORT CONDITION SURVEY SAFETY PLAN FOR PERRY MUNICIPAL AIRPORT, PERRY, IOWA IN JUNE 2021

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Perry Municipal Airport (PRO) in Perry, Iowa. This document was developed along with the data collection plan provided in Appendix M. Figures N-1 to N-3 show the travel plans for the research team, and Figures N-4 and N-5 highlight the PRO layout.

Data Collection Date: Thursday, June 30, 2021 (weather permitting)

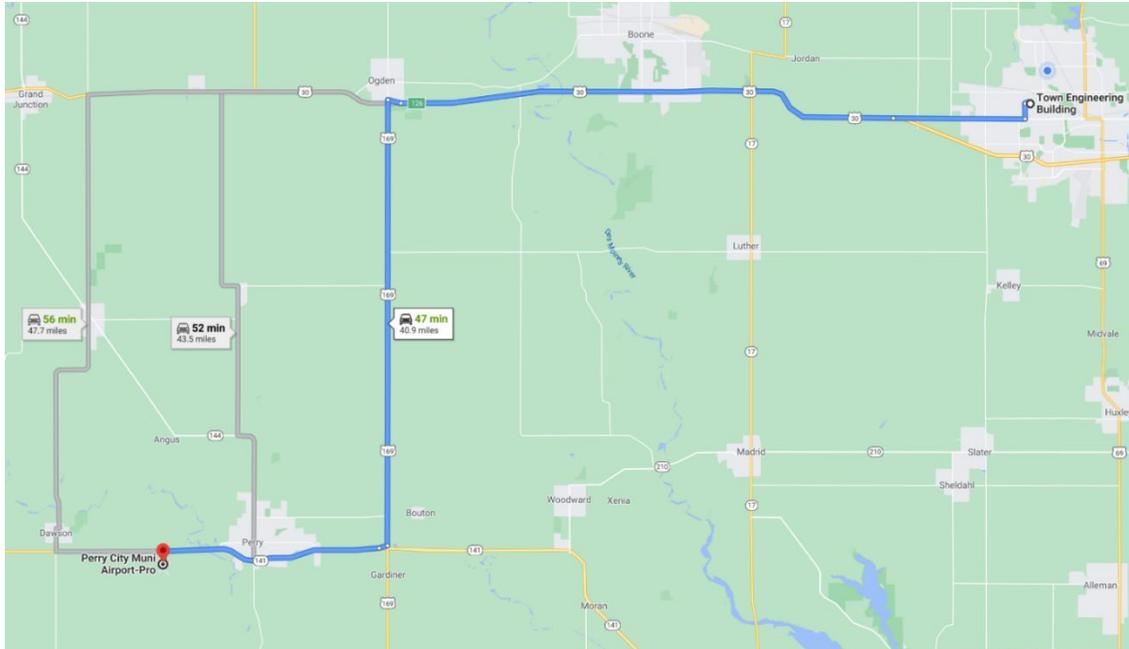


Figure N-1. Travel Route from Ames, Iowa to Perry Municipal Airport, Perry, Iowa

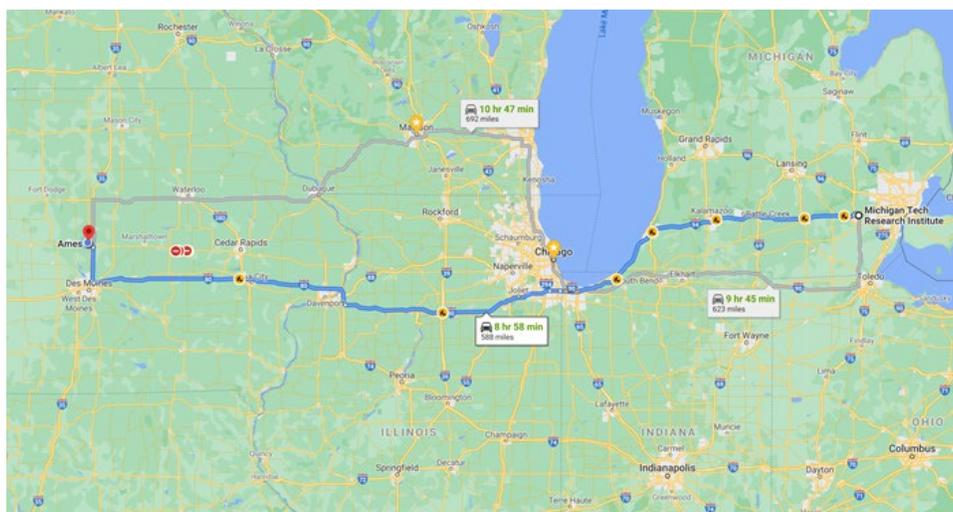


Figure N-2. Travel Route from Ann Arbor, Michigan to Ames, Iowa

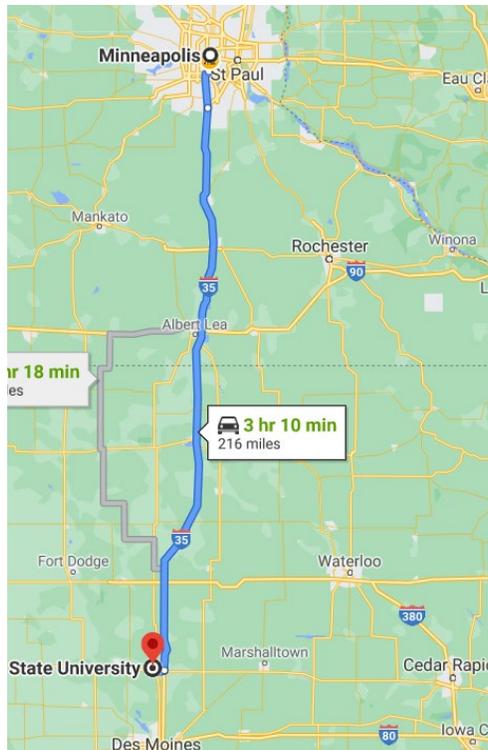


Figure N-3. Travel Route from Minneapolis, Minnesota to Ames, Iowa

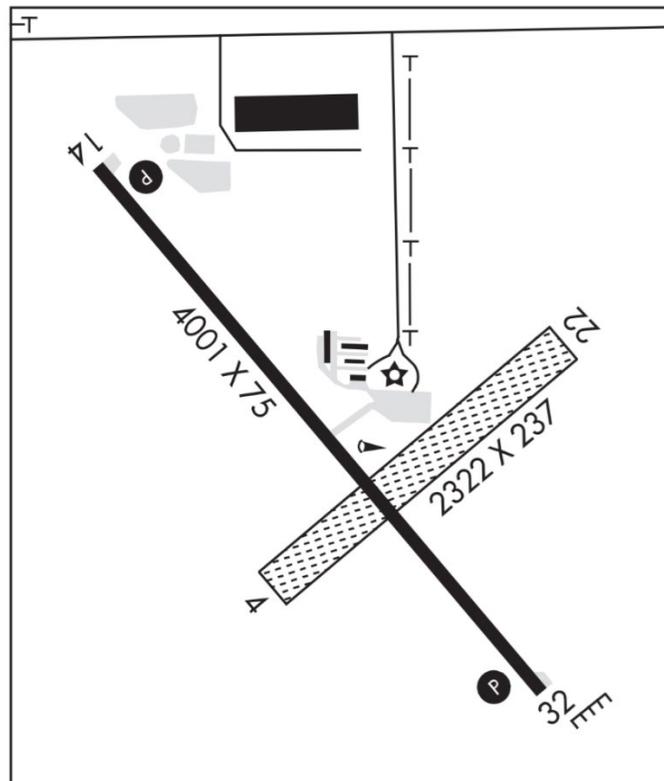


Figure N-4. Airport Diagram of Perry Municipal Airport, Perry, Iowa



Figure N-5. View of the Perry Municipal Airport, Perry, Iowa

## N.1 SAFETY INFORMATION

For any safety questions during field data collection, please contact:

- Halil Ceylan, Iowa State University (ISU) (Project Principal Investigator and Lead)
- Colin Brooks, Michigan Tech Research Institute (MTRI) (Project Lead and backup pilot and ground control collector)
- Richard Dobson (Lead Pilot-in-command)

Other participants include:

- Matthew T. Brynick, Federal Aviation Administration (FAA) (Civil Engineer, Airport Technology Research & Development)
- Abdullah Sourav, ISU (drone pilot)
- Chris Cook, MTRI (road & drone safety observer, backup pilot)
- Julie Carter, MTRI (ground control data collector, backup road and drone safety observer)
- Olivia Brouillette, ISU (undergraduate research assistant intern)
- Robin Valle, California State University (undergraduate research assistant intern).

Proposed schedule

- MTRI team will depart MTRI at 1 p.m. on June 28, arriving in Ames, Iowa at approximately 11:30 p.m. local time (travel time to Ames, Iowa from MTRI is around 9 hours minus the time change to Central time).
- Olivia Brouillette will depart from Minneapolis, Minnesota at 7 a.m. on June 28, arriving in Ames, Iowa at approximately 10 a.m. (travel time is approximately 4 hours).
- Robin Valle will depart from Los Angeles, CA at on June 27, arriving in Ames, Iowa at approximately 10 p.m. the same day.
- On June 30, the ISU and MTRI team will be arriving in Perry, Iowa at approximately 1:00 p.m. local time. Survey the airport on June 30 and return to Ames by leaving Perry at 5 p.m.
- On July 1, the ISU and MTRI team will depart Ames, Iowa at 8:00 a.m., arriving in Perry, Iowa at approximately 9:00 a.m. local time (travel time to PRO from Ames is approximately 50 minutes). Survey the airport on July 1, if required, and leave before 12:00 p.m.
- MTRI team will leave for MTRI on July 1.

## N.2 FIELD SITE

The data collection will be performed at Perry Municipal Airport (PRO), Perry, Iowa. The PRO airport manager is Jonathan Walter, who has agreed to sUAS field deployment. The general phone number for the airport is 515-465-3970.

## N.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on reflective vests, safety glasses, and appropriate clothing. Driving vehicles must have yellow caution lights present.

- A stand-up safety briefing will be held at the beginning of any data-collections days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (high-visibility vest and glasses) at all times.
- sUAS pilots MUST have an undistracted spotter watching for vehicle and air traffic and for the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- Team will be operating on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway or taxiway being surveyed by sUAS, operations will cease (land sUAS), then will continue after the manned aircraft have finished their takeoff or landing procedures.
- There will be two sUAS data-collection teams, with Richard Dobson (MTRI) and Abdullah Sourav (ISU) as the lead pilots for each team. Each team will have their own Sporty's® 400/ YEASU Spirit aviation radio, which will be on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 122.8 used for PRO.
- Julie Carter and Colin Brooks will place AeroPoint™ ground control points (GCPs) at the beginning of each day of data collection. Additional traditional cloth targets will be placed, if required, at the beginning of the first day and will have their locations recorded with a decimeter-resolution Global Positioning System (GPS).
- Windows of moving vehicles will be kept open, with vehicle radios off, to enable listening for unexpected aircraft when driving on runways and taxiways.
- Crew members should always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members should avoid standing on airfield pavement during data collections unless necessary.
- Crew members should not stand in open traffic lanes at the airport. If walking along an open stretch of roadway, walk against the flow.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the ends of the runway will be used, so the team should stay outside these areas when not completing a data collection. The team will stay away 76.2 m horizontally from any moving aircraft.

#### N.4 SMALL UNMANNED AIRCRAFT SYSTEM SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants a day prior to field collections of where the sUAS will be operating, safe places and minimum distance to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a Remote Pilots Certificate may not operate a sUAS unless

being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly.

- Remain a safe distance from and do not stand directly below a flying sUAS.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are being operated unless it is an immediate emergency.
- All sUAS operations MUST have a designated spotter.
- If any low-flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of sUAS operation in case of a battery fire.

## N.5 FIRST AID AND MEDICAL

- First aid kit will be on site with the field crew for all site visits.
- Emergency number is 911.
- Nearest hospital location to study site: Dallas County Hospital, Perry, Iowa 50220 (5 km, 7 minutes).
  - 610 10th St, Perry, Iowa 50220. Phone: 515-465-3547 (non-emergency).
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead) . Any workplace injury must be reported to Ms. Philips, and appropriate forms filled out if medical care is sought due to any workplace injuries.
- ISU phone number: (515)-294-8213, Paul Kremer (Manager Research, CCEE, ISU). Any workplace injury must be reported to Mr. Kremer if medical care is sought due to any workplace injuries.

## N.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- **Notes:** Most states have lifted COVID-19 restrictions. More information on Iowa COVID-19 guidance is available at: <https://coronavirus.iowa.gov/> and <https://coronavirus.iowa.gov/pages/guidance>.
- ISU's COVID-19 Safety Plan
  - The COVID-19 guidelines have been updated for regent institutions in Iowa on May 20, 2021. Mask use continues to be encouraged for those who have not been vaccinated, and optional for those who have been vaccinated.
  - Travelers have been encouraged to adhere to CDC guidance for domestic travel.
  - All details are available at the following web addresses:
    - COVID-19 guideline update for regent institutions in Iowa: <https://www.iowaregents.edu/news/board-news/statement-from-president-mike-richards-lifting-regents-state-of-emergency>
- ISU safety and health policy resources: <https://web.iastate.edu/safety/>
- ISU safety policy on COVID-19: <https://web.iastate.edu/safety/updates/covid19>
- ISU gathering and events policy: <https://web.iastate.edu/safety/updates/covid19/events-gatherings>

- ISU Civil, Construction, and Environmental Engineering (CCEE) safety resources: <https://www.ccee.iastate.edu/safety/>
- ISU CCEE research and instructional labs and fieldwork safety policies: <https://www.ccee.iastate.edu/files/2019/07/CCEE-Laboratory-Policies-and-Guidelines-CCEE-Safety-and-Health-Committee-and-EHS-Reviewed-and-Approved-2.23.2-3.pdf>
- MTRI's COVID-19 Safety Plan
  - MTRI's COVID-19 safety plans have been as follows, which unvaccinated participants are expected to follow closely:
    - Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
    - Field crew travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
    - Field equipment will be individually assigned as much as possible (for example, whomever starts with a particular sUAS will use that one throughout the day) and will be disinfected with Lysol®-type wipes when possible.
  - Multiple workers are allowed to travel within the same vehicle when the University's Health and Safety Level is at Level 2.
  - As of 6/22/2021, the University is at Level 2. (<https://www.mtu.edu/flex/operations/levels/>)
  - Note that there is a cleaning protocol for the MTRI Durango that MUST be followed – laminated copies can be found inside the Durango.
  - Work is to comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
    - COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
    - Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
    - Research Pandemic Checklist: [Research Pandemic Checklist - Google Docs](#)
  - Now that the University is back at Level 2, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/ Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

## APPENDIX O—SMALL UNMANNED AIRCRAFT SYSTEM DATA COLLECTION PLAN FOR CAPE MAY AIRPORT, CAPE MAY, NEW JERSEY IN AUGUST 2021

This small unmanned aircraft system (sUAS) data collection plan was developed to safely collect data from Cape May Airport (WWD) in Cape May, New Jersey. This document is developed along with the safety plan provided in Appendix P.

Data Collection Date: August 23-26, 2021

### O.1 SMALL UNMANNED AIRCRAFT SYSTEM REQUIRED

- DJI Mavic 2 Pro with integrated 20-megapixel (mp) camera (2 systems) with spare batteries [charged]
  - Controller [charged]
  - Integrated Controller [charged]
  - Spare 4G Pixel™ phone as a backup controller [charged]
- DJI Mavic 2 Enterprise Advanced (M2EA) with integrated dual 48-mp camera and 640 x 512 thermal camera [two systems – one from Michigan Tech Research Institute (MTRI) and one from Iowa State University (ISU)]
  - Seven batteries from MTRI and six batteries from ISU [charged]
  - Smart Controller for each drone [charged]
- Bergen Hexacopter with spare batteries [charged]
  - Controller [charged]
  - First-person view (FPV) screen [charged]
  - Optical camera (Nikon D850 45.7 mp) [batteries charged]
- mdMapper-1000+ with spare batteries [charged]
  - Controller [charged]
  - Optical camera (Sony RX1R-II 42.4 mp) [batteries charged]
- Tarot X6 V2.2 with spare batteries [charged]
  - Controller [charged]
  - Optical camera (Nikon D850 45.7 mp) [batteries charged]
  - Herelink video transmission system [batteries charged]

### O.2 OTHER EQUIPMENT

- Propeller AeroPoint™ electronic Global Positioning System (GPS)-based ground control targets (20)
- Micro-SD cards/spare micro-SD cards with SD card adapter + full-sized SD cards [past data stored/removed]
- 2xPortable 1 TB SSD
- 256 GB pendrive
- Folding takeoff pad
- Generator and gas can
- Rugged Olympus Tough TG-5® GPS Camera (12 mp) - (for geolocated field photos) (2) [charged]
- Sony Alpha Camera (16 mp) for field photos (withwith zoom lens) (1) [charged]

- MTRI flight logging form (at least 2 copies), completed with information for documenting flight details
- Sporty's® SP-400 (2) and Yaesu® FTA 750L (1) aviation radios, tuned to Cape May Airport (WWD), Cape May, New Jersey Unicom frequency **122.7** for the entire time the team is onsite at WWD
  - Two aviation radios are provided for every two-person sUAS flight team. The third radio is provided for the person(s) placing ground control points (GCPs) or moving on the airfield so that they can operate in separate parts of the airport, completing needed tasks more quickly while staying safe and aware of manned and unmanned aircraft operations on or near WWD.
- Anemometer (for checking wind speed)
- iPad® Mini with GeoPDF airport map that includes recommended GCP locations to assist with placing GCPs
- Clipboard
- Field books/personal notebook
- Pens and pencils
- Measuring tape
- Ruler (30 cm)
- Tools and tape
- Appropriate clothing and protective eyewear
- Steel/composite toe boots/shoes
- Facemasks (see COVID-19 portion of the safety plan)
- First aid kit(s) – at least one
- Emergency beacon lights
- Traffic cones
- Fire extinguisher (1)
- Bottled waters
- Appropriate clothing

All batteries will be charged, and equipment will be packed and placed the day prior to travel to Cape May, New Jersey.

### O.3 AIRPORT CONTACT INFORMATION

The senior airport manager of WWD is Thomas Berry, who has agreed to sUAS field deployment. The general phone number for the airport is (609) 886-8652.

Airport webpage: <http://www.capemayairport.com/>

SkyVector webpage about WWD: <https://skyvector.com/airport/WWD/Cape-May-County-Airport>

#### O.4 FOCUS AREAS FOR DATA COLLECTION

Data collection will focus on Runway 10/28 and Apron at WWD. The runway has six different asphalt overlay over asphalt concrete (AAC) pavement sections. The plan is to collect data from three of them: RW1028CM10N, RW1028CM10C, and RW1028CM10S. The dimensions of the Runway 10/28 are 1,523.34 m x 45.7 m. Each section of the runway being focused on is 1242.1 m long and 15.2 m wide.

According to a pavement condition index (PCI) inspection survey conducted by Applied Research Associates, Inc. (ARA) in 2019, the area-weighted average PCIs for RW1028CM10N, RW1028CM10C, and RW1028CM10S were 67, 71, and 50, respectively, as shown in Table O-1. Severity is rated as high (H), medium (M), or low (L) or a combination of the three. The PCI survey also noted that the focus areas of the runway had joint reflection cracking (L), longitudinal and transverse (L&T) cracking (LM), rutting (LM), depression (M), patching (L), and weathering (L). This PCI report was provided by Federal Aviation Administration (FAA).

The aprons consist of six sections of asphalt concrete (AC) and one section of Portland cement concrete (PCC) pavements. The branch had a total area of 73,719.7 square m, and the area-weighted average PCI was 62 (Fair). However, the plan is to collect sUAS data from section 30 with AC pavement and section 40 with PCC pavement. The PCC pavement of the Apron showed a wide variety of distresses that includes corner break (L), corner spalling (LMH), corrugation (L), faulting (LM), joint seal damage (LM), joint spall (LMH), large patch (LMH), LTD cracks (LMH), pop-outs, and small patch (LMH). The dominant PCC pavement distresses are corner spall, Diagonal crack (D-crack), faulting, joint spall, large patch, small patch, shrinkage crack, and LTD crack (Table O-1).

The PCI value for the PCC section of the Apron in 2019 was 58, whereas section 30 with AC pavement had a PCI value of 72. Section 30 had L&T cracking (LM), raveling (L), and weathering (L) throughout the whole pavement.

Table O-1. The PCI Survey Result of the Data Collection Area

Branch ID	Section ID	Surface Type	2019 PCI	Area	Distresses
ATERMCM	30	AC	72	152467	L&T cracking (LM), raveling (L), weathering (L)
	40	PCC	58	2335	Corner break (L), corner spalling (LMH), corrugation (L), faulting (LM), joint seal damage (LM), joint spall (LMH), large patch (LMH), LTD cracks (LMH), pop-outs, and small patch (LMH)
RW1028CM	10C	AAC	71	203750	Joint reflection cracking (L), L&T cracking (LM), weathering (L)
	10N	AAC	67	203750	L&T cracking (L), rutting (L), weathering (L), patching (L)
	10S	AAC	50	204931	L&T cracking (LM), rutting (LM), weathering (L), patching (L)

L= Low severity, M= Medium severity, H= High severity  
 AC= Asphalt concrete pavement  
 PCC= Portland cement concrete pavement  
 AAC= Asphalt overlay over asphalt concrete  
 L&T cracking = Longitudinal and transverse cracking  
 LTD cracking = Longitudinal, transverse, and diagonal cracking

#### O.4.1 High-Resolution Data Collection Sample Units

Nine sample units (SUs) are selected for high-resolution data collection. These SUs have AC, AAC, and PCC pavements, with most of the airfield pavement distresses found at WWD. Three AAC sample units from Runway 10/28, three AC sample units from Apron section 30, and three PCC sample units from Apron 40 were selected, as shown in the Figure O-1. The Runway SUs are noted to have L&T cracking, weathering, and depression. Conversely, the Apron 30 sample units exhibited L&T cracking, swell, and shoving due to movement of PCC pavements. The four selected PCC SUs had LTD cracks, joint spalling, shrinkage crack, joint seal damage, small patching, large patching, and scaling. The sample units will also have higher priority in PCI data collection by Applied Pavement Technology, Inc. (APTech). They have been marked as level 1, or high-priority sample areas. A detail of the PCI data-collection SUs and their priority levels is provided in Table O-2.

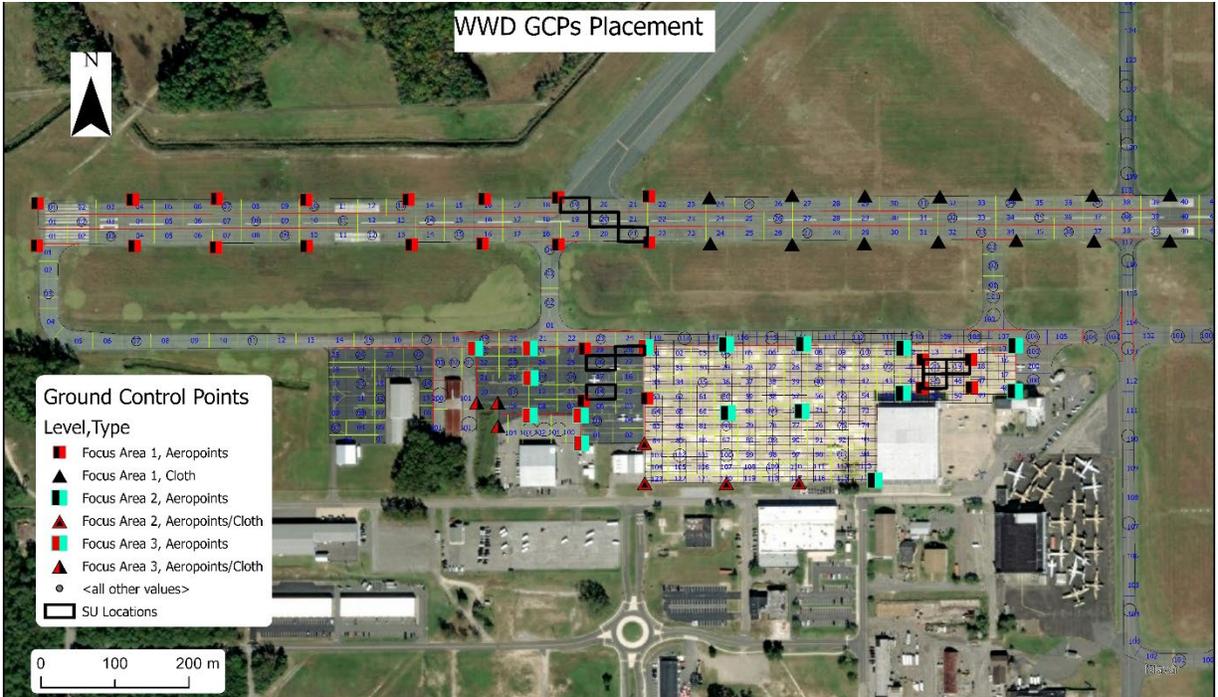


Figure O-1. Overview of WWD and Sampling Focus Areas, Including Recommended Locations for GCPs

## O.5 OBJECTIVES FOR UPCOMING AUGUST 2021 sUAS DATA COLLECTION

### O.5.1 Bergen Hexacopter or Tarot X6

The Bergen Hexacopter or Tarot X6 with Nikon D850 will be flown at 18.3 m to collect optical imagery of Runway 10/28 section 10 and Apron Sections 30 and 40. At 60 feet, the red, green, blue (RGB) optical imagery will be 1.49-mm resolution. In addition, the same system will be flown at 9.1 m over the selected sample units to collect very high-resolution optical RGB data. Because the selected SUs are close, they will be covered in three manual flights: one for runway SUs, one for AC section of the Apron SUs, and one for the PCC section of the Apron SUs. Each flight will require 3 to 10 minutes to complete, depending on how far apart the paired SUs are. At 9.1 m, the RGB optical imagery will be 0.75-mm resolution. The Tarot X6 flight will be operated using the software that comes with the Pixhawk controller. Conversely, manual control is identified because of the small areas planned for data collection and the older Bergen flight control hardware and software not being compatible with current mission planning applications.

Table O-2. Data Collection Priority Level

Priority Level	Airfield	Pavement Type	Section	Sample Unit
1	RW1028	AAC	CM10N	19
			CM10C	20
			CM10S	21
	ATERM	AC	CM30	14, 26, 28
	ATERM	PCC	CM40	19, 20, 45
2	RW1028	AAC	CM10N	1, 7, 10, 13, 25, 31, 34, 37
			CM10C	2, 8, 11, 14, 26, 32, 35, 38
			CM10S	3, 9, 12, 15, 27, 33, 36, 39
	ATERM	AC	CM30	3, 11, 18, 19, 23, 33
		PCC	CM40	4, 10, 22, 35, 40, 55, 60, 64, 69, 75, 80, 89, 95, 100, 102, 109

### O.5.2 mdMapper-1000+

The team also has a German-made mdMapper-1000+ UAS for photogrammetric optical data collection. The mdMapper-1000+ was purchased in 2020 to detect map defects on bridge decks and measuring 3D rates of construction progress. This system has been flown at 18.3 m above ground level (AGL) with lesser winds and turbulence at Custer Airport (TTF) in Monroe, Michigan and Coles County Memorial Airport (MTO) in Mattoon, Illinois. The mdMapper-1000+ is currently configured to collect data with a 42.4-mp Sony RX1R-II. At 18.3 m, the optical imagery will have a 2.3-mm resolution.

### O.5.3 Mavic 2 Pro

Optical imagery is planned to be collected at 15.2 m AGL with the Mavic 2 Pro 20 mp for Runway 10/28 section 10 and Apron Sections 30 and 40 as a backup dataset. MTRI is planning to bring two Mavic 2 Pro sUAS with additional batteries. A total of at least seven preplanned missions is likely needed to cover the focus areas.

The flight plans for these missions are created with the Pix4D Capture or DroneDeploy android application, which has been successfully used in mission planning for previous data collection in this research. An 80% forward overlap and a 70% side overlap are being used, which is standard for most of the missions where close-range photogrammetry software is used to create orthophotos and digital elevation model (DEM) outputs. These overlap settings were used successfully to create outputs for different flights at TTF in Monroe, Michigan; Grosse Ile Municipal Airport (ONZ) in Grosse Ile Township, Michigan; Coles County Memorial Airport (MTO) in Mattoon, Illinois; Boone Municipal Airport (BNW) in Boone, Iowa; and Perry Municipal Airport (PRO) in Perry, Iowa. Figures O-2 through O-4 show drafts of the preplanned missions for a runway mission at 15.2 m using the Mavic 2 Pro sUAS. The details of the flight plans are provided in Table O-3.

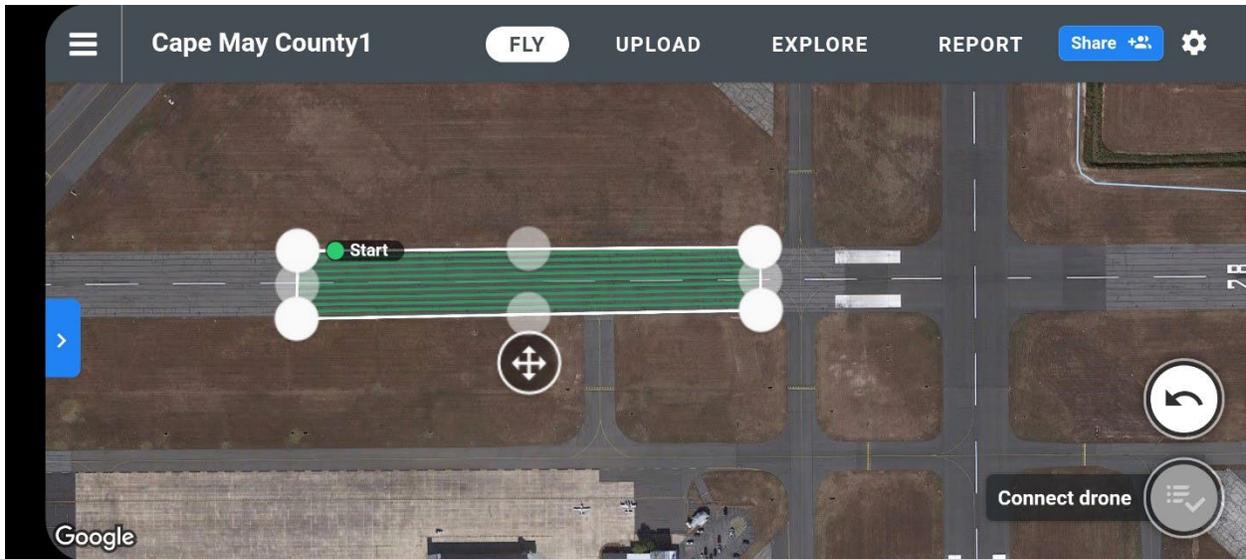


Figure O-2. Mavic 2 Pro Flight Plan for Runway 10/28

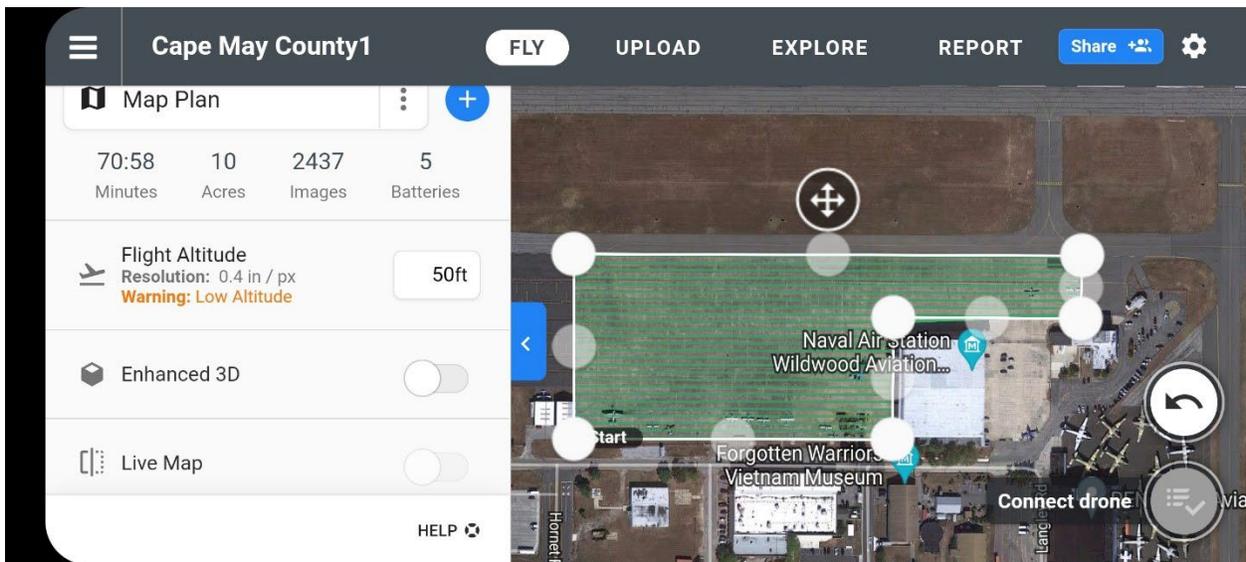


Figure O-3. Mavic 2 Pro Flight Plan for Apron Section 40

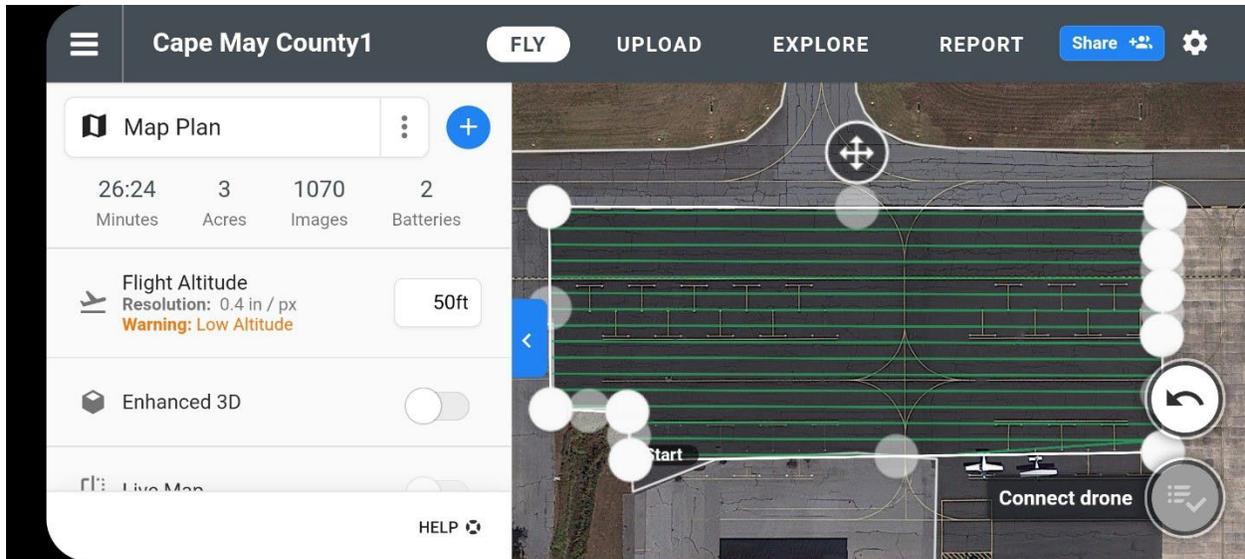


Figure O-4. Mavic 2 Pro Flight Plan for Apron Section 30

Table O-3. Planned Sensors and Flying Heights for All sUAS

Date	Target Area	sUAS Platform	Sensors	AGL m	Expected Resolution mm/pix
8/24	SUs	Bergen Hexacopter or Tarot X6	45.7-mp optical RGB Nikon D850	9.1	0.8
		mdMapper-1000+	42.4-mp optical RGB Sony RX1R-II	18.3	2.3
8/24 to 8/26	RW1028CM10N, RW1028CM10C, RW1028CM10S, TWECM10, TWECM20, ATERMCM30, and ATERMCM40	Bergen Hexacopter or Tarot X6	45.7-mp optical RGB Nikon D850	18.3	1.5
		Mavic 2 Enterprise Advanced	640 x 512 stereo thermal	24.4	3.1
		Mavic 2 Pro	20-mp optical RGB	15.2	3.7

SU = Sample unit

AGL = Above ground level

Mavic 2 Pro RGB optical data will be collected as a backup if required.

### O.5.4 Mavic 2 Enterprise Advanced

Thermal imagery will be collected over Runway 10/28 section 10 and Apron Sections 30 and 40. Two M2EA units will be available, one with seven batteries and one with six batteries. Batteries can be recharged during the day with an available generator. The average flight time is estimated at 20 minutes per battery. The stereo thermal data is from 24.4 m AGL. The preplanned flights are shown in Figure O-5 and O-6. The details of the flight plans are provided in Table O-2.

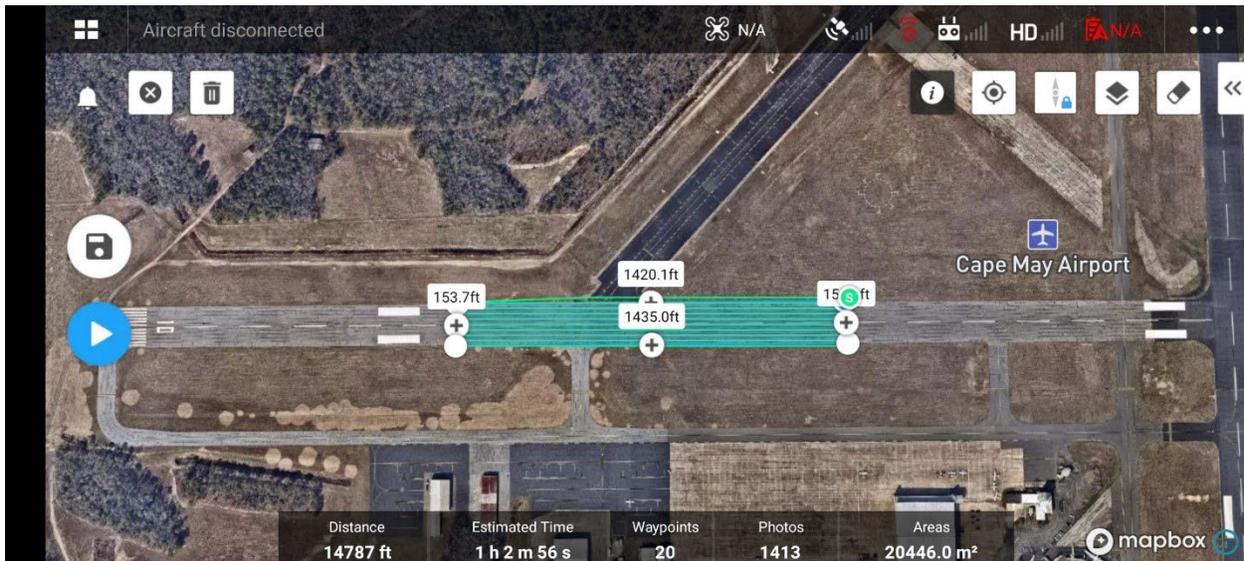


Figure O-5. Flight Plan for Stereo Thermal Data Collection with M2EA Over Part of Runway 10/28



Figure O-6. Flight Plan for Stereo Thermal Data Collection with M2EA over Apron Section 30

## O.6 PILOTS AND SUPPORT TEAM

The research team has four research staff available for flying the sUAS, all of whom have a current Part 107 Unmanned Pilot's Certificate. Other crew members can help with GCP GPS data collection and capturing pavement distress images. The standard procedure is to have at least two staff members for each UAS flight: one UAS pilot and one safety observer. In simultaneous data collection, each sUAS pilot will have a dedicated field observer. WWD is a class G airspace. Therefore, none of the sUAS pilots will need any approval for flying sUAS under 121.9 AGL.

*Provisional timeline for data collection day – All timing is subject to change based on weather conditions and airport operations.*

The research team will travel to Cape May, New Jersey, from Iowa, Michigan, and Illinois on August 22 and 23, 2021. The research team will take part in any training or paperwork needing to be completed before entering the airfield or driving personnel vehicles. Once the research team is on the airfield, the GCPs will be placed, then data will be collected from the SUs using the remote pilot-in-command. This will be followed by data collection over the other parts of the airfield by different pilots. The main objective for the day is to collect the high-resolution sample unit data first. If time allows, as much data as possible from Runway 10/28 and Apron Sections 30 and 40 will be collected on the same day. The remaining data will be collected on August 25 and 26, 2021.

The data-collection team will have their aviation radio on at all times for data collection on Unicom frequency 122.7 used for WWD. Communications via the radio should be in the form of "Cape May. [Announcement]. Cape May."

Windows of moving vehicles will be kept open, with vehicle radios off, to listen for unexpected aircraft when driving on runways and taxiways. The team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside the Runway Safety Area. A representative Runway Safety Area of 76.2 meters from the runway centerline and 304.8 m from the runway ends is being used, so the team will stay outside these areas when not collecting data. Team will keep away 76.2 m horizontally from any moving aircraft and will not operate sUAS if wind gusts exceed 24 kmph and temperatures are above 37.78°C. A hand-held anemometer will be used to measure wind speed before each mission.

Following is the planned data collection timeline:

### **August 23, 2021**

8:30 a.m. – 5:00 p.m.: PCI data collection by APTEch  
5:00 p.m. – 5:30 p.m.: PCI data collection conclusions

## August 24, 2021

8:30 a.m. – 9:00 AM: Paperwork, training, and stand-up meeting lead by the remote pilot-in-command

8:30 a.m. – 5:00 p.m.: PCI data collection by APTEch

9:00 a.m. – 9:30 a.m.: AeroPoints and Ground Control Points based on the ground control placement map

9:30 a.m. – 5:00 p.m.:

- Remote Pilot-in-command with Bergen Hexacopter or Tarot X6 data collection
  - Sample Units
    - Bergen Hexacopter or Tarot X6 at 9.1 m AGL
      - Estimated Total Time: 30 mins or 20 mins
    - mdMapper1000+ at 18.3 m AGL
      - Estimated Total Time: 15 mins
  - Runway 10/28 Section 10
    - Bergen Hexacopter or Tarot X6 at 18.3 m
      - Estimated Total Time: 2.9 hours or 3.3 hours
- Pilot 2 and Pilot 3
  - Runway 10/28 Section 10
    - Mavic 2 Pro at 15.2 m
      - Estimated Total Time: 2 hours
    - Mavic 2 Enterprise Advanced at 18.4 m stereo thermal data
      - Estimated Total Time: 3 hours

5:00 p.m. – 5:30 p.m.: GCPs collection and PCI and sUAS data collection conclusions

## August 25, 2021

8:30 a.m. – 9:00 a.m.: Paperwork, training, and stand-up meeting lead by the remote pilot-in-command

8:30 a.m. – 5:00 p.m.: PCI data collection by APTEch

9:00 a.m. – 9:30 a.m.: AeroPoints and GCPs based on the ground control placement map

9:30 a.m. – 5:00 p.m.:

- Remote Pilot in command with Bergen Hexacopter or Tarot X6 data collection.
  - Any remaining data from 8/24
  - Apron Section 30
    - Bergen Hexacopter or Tarot X6 at 18.3 m
      - Estimated Total Time: 1.4 hours or 1.2 hours
  - Apron Section 40
    - Bergen Hexacopter or Tarot X6 at 18.3 m
      - Estimated Total Time: 2.2 hours or 2 hours
- Pilot 2 and Pilot 3
  - Any remaining data from 8/24
  - Apron Section 30
    - Mavic 2 Pro at 15.2 m
      - Estimated Total Time: 0.5 hour

- Mavic 2 Enterprise Advanced at 18.3 m stereo thermal data
    - Estimated Total Time: 1 hour
  - Complete Apron Section 40
    - Mavic 2 Pro at 15.2 m
      - Estimated Total Time: 1.8 hours
    - Mavic 2 Enterprise Advanced at 18.3 m stereo thermal data
      - Estimated Total Time: 2.5 hours
- 5:00 p.m. – 5:30 p.m.: Ground control points collection and PCI and sUAS data collection

**August 26, 2021**

- 8:30 a.m. – 9:00 a.m.: Paperwork, training, and stand-up meeting led by the remote pilot in command
- 9:00 a.m. – 9:30 a.m.: AeroPoints and Ground Control Points based on the ground control placement map
- 9:30 a.m. – 5:00 p.m.:
- Remote Pilot in command with Bergen Hexacopter or Tarot X6 data collection.
    - Any remaining data from 8/24 and 8/25
  - Pilot 2 and Pilot 3
    - Any remaining data from 8/24 and 8/2
- 5:00 p.m. – 5:30 p.m.: GCPs collection and data collection conclusions

**August 27, 2021**

Back-up date.

The data-collection schedule is developed based on the weather condition shown on the forecast. The weather forecast shows mostly sunny or sunny on August 24 to 26, 2021 (Figure O-7). However, the data-collection team will closely monitor.

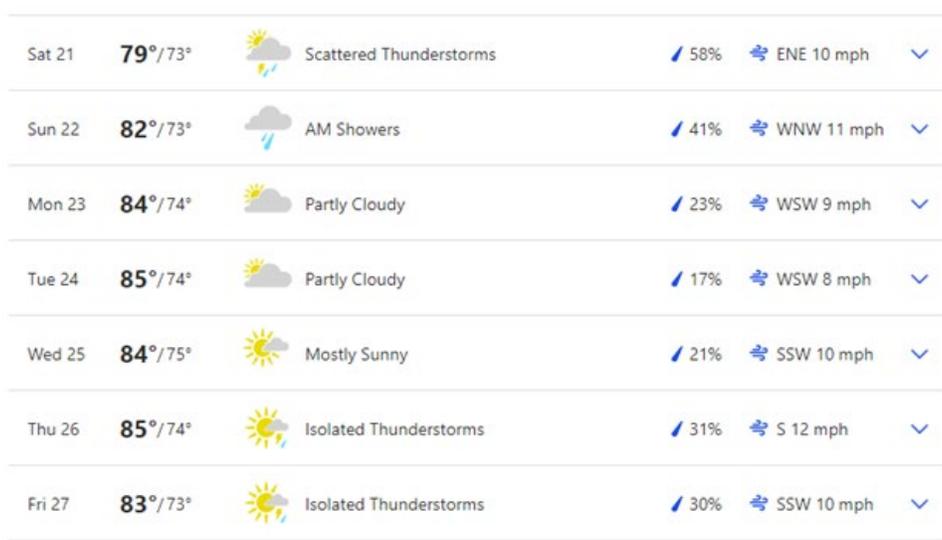


Figure O-7. Weather Forecast for Cape May, New Jersey (as of August 16, 2021)

All missions will be documented by a photographer designated for each mission, who is not flying the UAS or acting as an observer (this is usually one of the GCP data collection crew members). A separate safety plan has also been completed and shared and will be reviewed no later than 3 days ahead of the deployment date if any final modifications are needed.

## APPENDIX P—AIRPORT CONDITION SURVEY SAFETY PLAN FOR CAPE MAY AIRPORT, CAPE MAY, NEW JERSEY IN AUGUST 2021

This safety plan was developed for safe small unmanned aircraft system (sUAS) data collection from Cape May Airport (WWD) in Cape May, New Jersey. This document was developed along with the data collection plan provided in Appendix O. Figures P-1 to P-3 show the travel plans for the research team, and Figures P-4 and P-5 highlight the WWD layout.

Data Collection Date: August 23 and 26, 2021

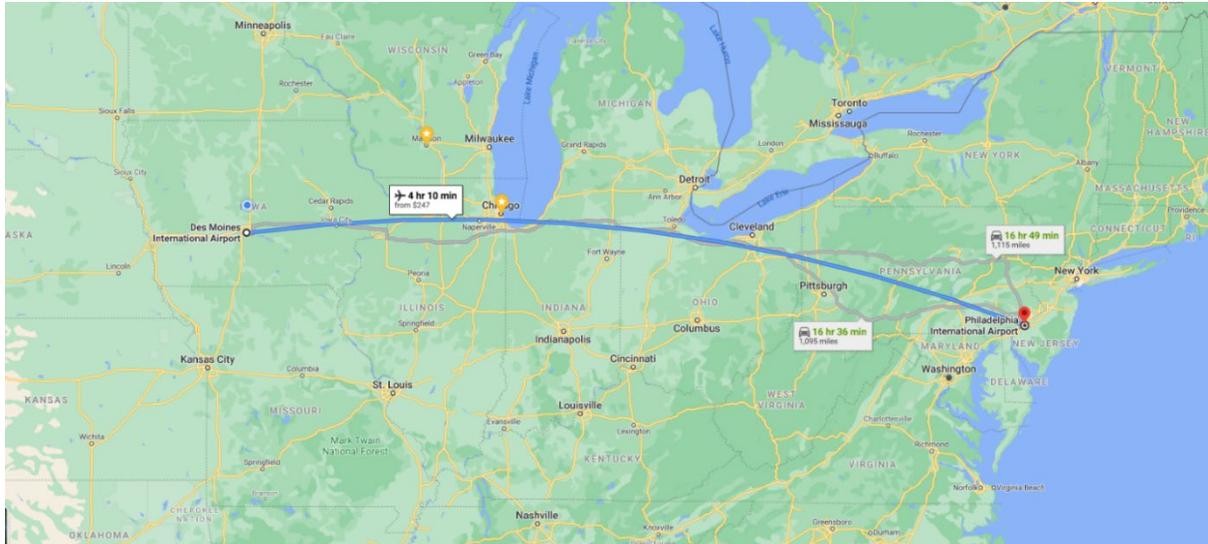


Figure P-1. Air Travel Route from Des Moines, Iowa to Philadelphia, Pennsylvania

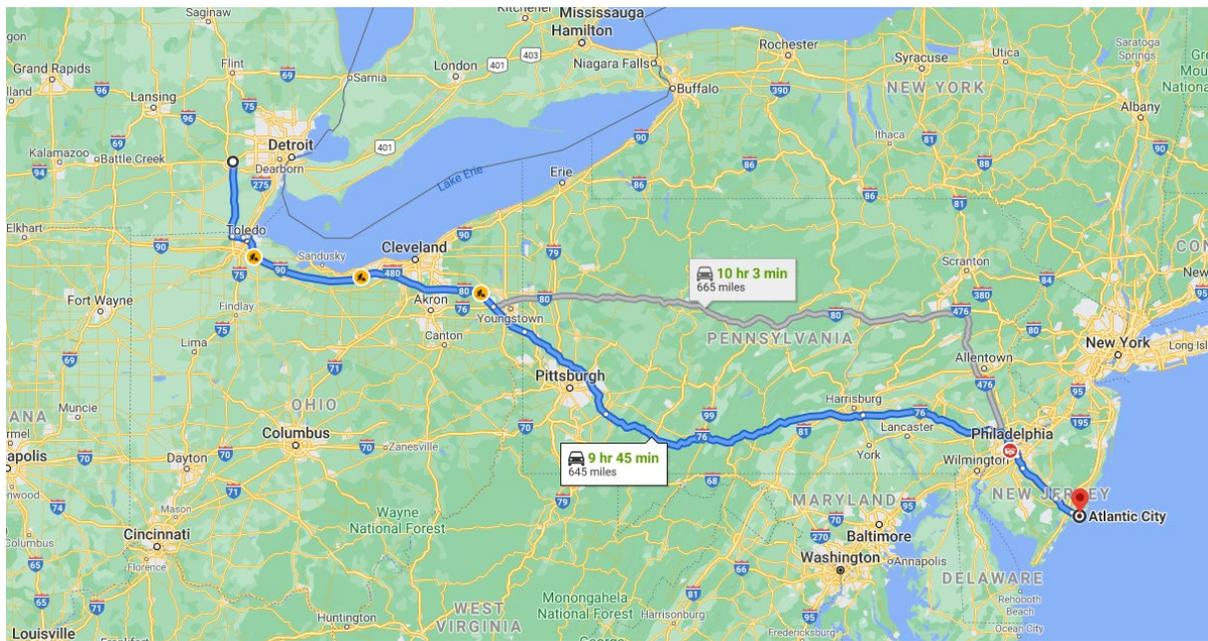


Figure P-2. Travel Route from Ann Arbor, Michigan to Atlantic City, New Jersey

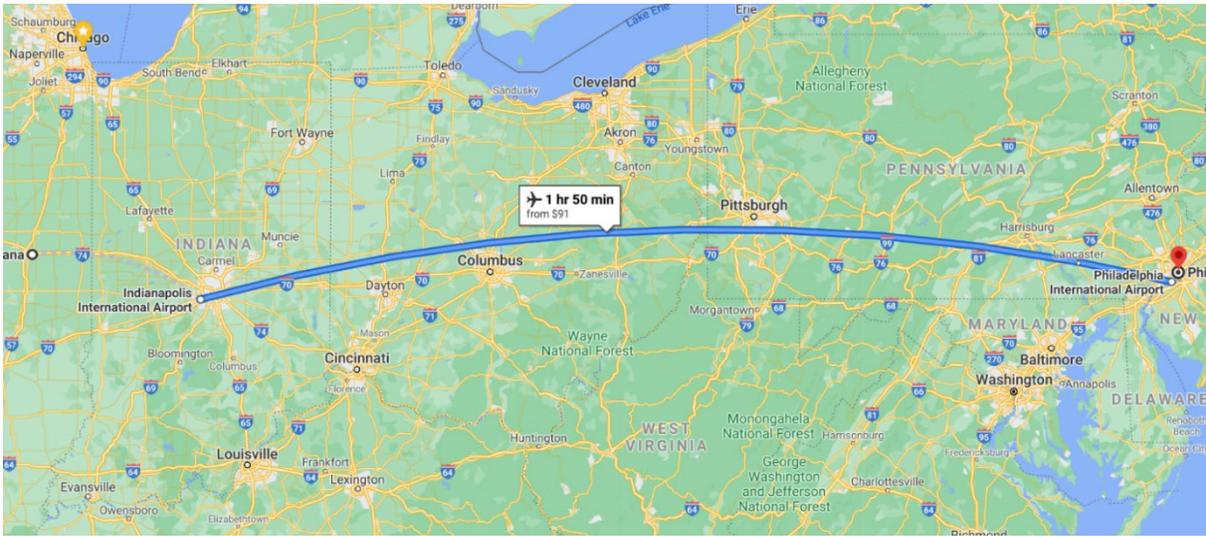


Figure P-3. Travel Route from Indianapolis, Indiana to Philadelphia, Pennsylvania

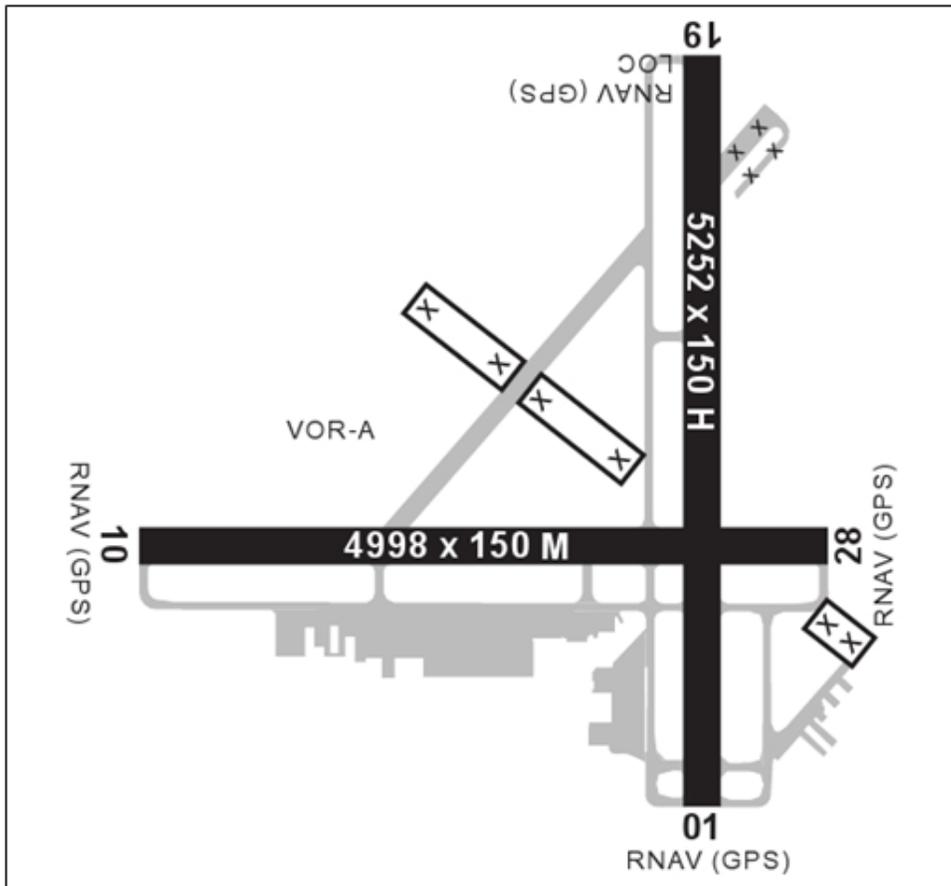


Figure P-4. Airport Diagram of Cape May Airport, Cape May, New Jersey

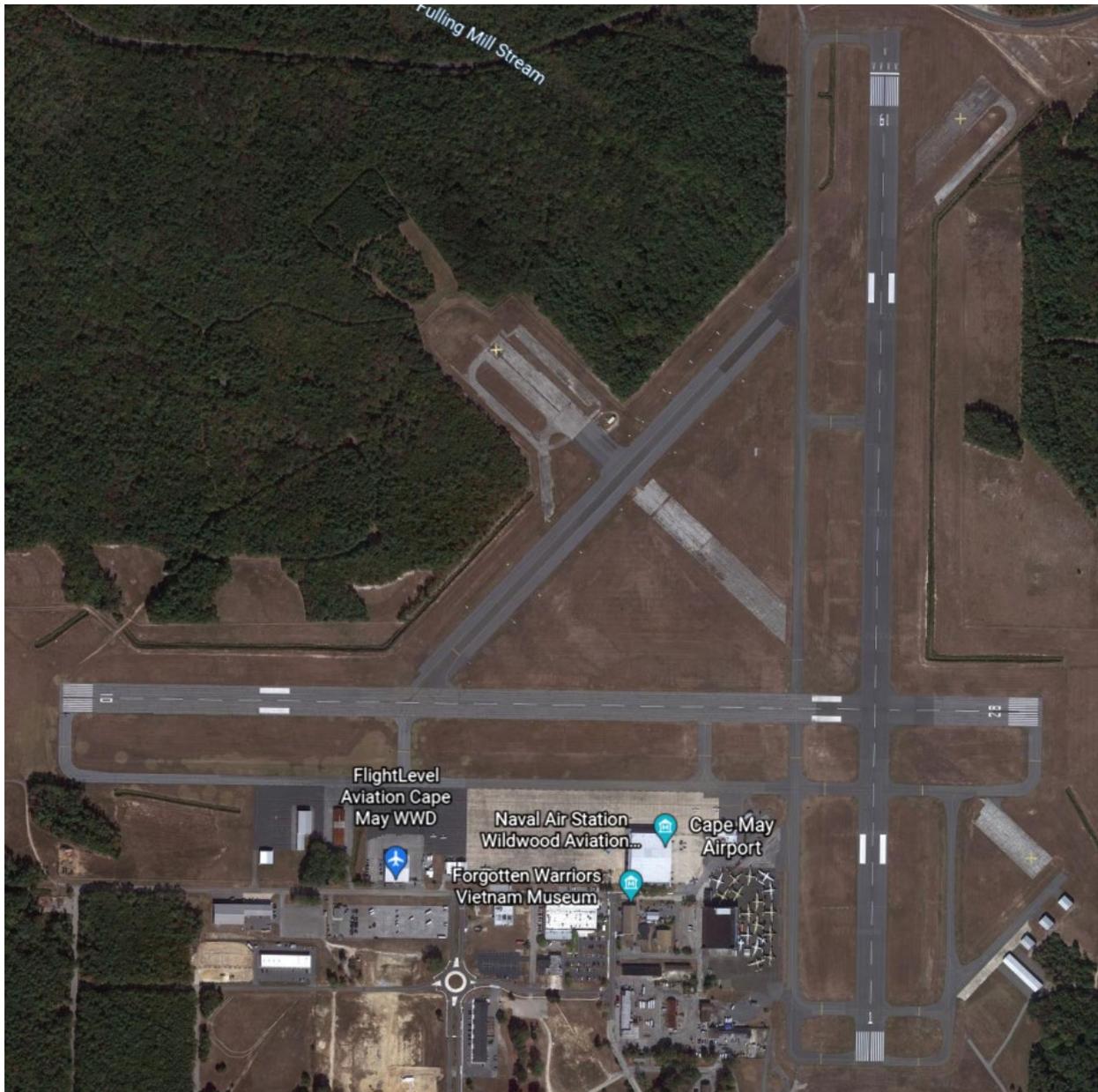


Figure P-5. View of WWD in Cape May, New Jersey

## P.1 SAFETY INFORMATION

**For any safety questions during field data collection, please contact:**

- Halil Ceylan, Iowa State University (ISU) (Project Principal Investigator and Lead)
- Colin Brooks, Michigan Tech Research Institute (MTRI) (Project Lead and backup pilot, ground control collector)
- Richard Dobson (Lead Pilot-in-command)

**Other participants are:**

- Abdullah Sourav, ISU (drone pilot)
- Chris Cook, MTRI (road & drone safety observer, backup pilot)
- Olivia Brouillette, ISU (undergraduate research assistant intern)
- Abby Jenkins, MTRI (ground control data collector, backup road and drone safety observer)
- David Peshkin, APTEch (APTEch project lead)
- Trent Montgomery, APTEch (Pavement condition index (PCI) inspector)
- Katie Gauthier, APTEch (PCI inspector)

**Proposed schedule**

- ISU team will depart Ames, Iowa in the morning on August 23, 2021, arriving in Atlantic City by evening on the same day. The airport of departure is Des Moines International Airport (DSM), and airport of arrival is Philadelphia International Airport (PHL).
- MTRI team will depart Ann Arbor, Michigan at 8 a.m. on August 23, 2021, arriving in Atlantic City approximately 10 p.m. on the same day (travel time to Atlantic City, New Jersey from MTRI is approximately 10 hours minus the time change).
- The PCI inspectors of APTEch. will depart Urbana, Illinois on August 22, 2021, arriving in Cape May by evening on the same day. The APTEch project lead will travel to Cape May on August 23, 2021
- The data collection team will commute from Atlantic City, New Jersey to WWD each day.
- The PCI survey will be conducted from August 23 to August 25, 2021.
- The sUAS data collection team will survey the airport on August 24 to 26, 2021, as needed.
- Return to Ames, Iowa on August 27, 2021.
- Return to Ann Arbor, Michigan on August 27, 2021.
- Return to Urbana, Illinois on August 25 and 26, 2021.

## P.2 FIELD SITE

Cape May Airport (WWD) is in Cape May, New Jersey. The senior airport manager of WWD is Thomas Berry, who has agreed to sUAS field deployment. The general phone number for the airport is (609) 886-8652.

### P.3 AIRPORT SAFETY

At all times on the fieldwork site, crew members must have on hard hats and reflective vests. Driving vehicles must have yellow caution lights present.

- A stand-up safety briefing will be held at the beginning of any data-collections days. After data collection, input will be sought from crew members on any safety concerns that may have come up.
- All crew members on the field site must be wearing protective clothing (steel- or composite-toe boots, high-visibility vest, glasses) at all times.
- Drone pilots MUST have an undistracted spotter watching for vehicle and air traffic, and for the safety of the pilot. The spotter will control an aviation radio and have the option of sharing control with an additional crew member.
- The team will be operating on a give-way basis to any air traffic at the airport. If manned aircraft are preparing to take off, approaching for a landing along the runway or taxiway being surveyed by sUAS, the team will cease operations (land sUAS) and continue them after the aircraft have finished their takeoff or landing procedures.
- The data-collection team will have two sUAS data-collection teams, with Richard Dobson (MTRI) and Abdullah Sourav (ISU) as the lead pilots for each team. Each team will have their own Sporty's® 400/ YEASU® Spirit aviation radio, which will be on at all times while performing data-collection operations (including setup and takedown time) on Unicom frequency 122.7 used for WWD.
- Abby Jenkins and Colin Brooks will place the AeroPoint™ GCPs at the beginning of each day of data collection . Additional traditional cloth targets will be placed at the beginning of the first day and have their locations recorded with a decimeter-resolution GPS. Both sets of targets will be placed off the runway and aprons.
- Windows of moving vehicles will be kept open, with vehicle radios off, to enable listening for unexpected aircraft when driving on runways and taxiways.
- Crew members should always be conscious of the presence of moving traffic or aircraft. Because of the presence of restricted airspace, pilots and spotters must be conscious of potential aircraft moving through the survey area.
- If one crew member is taking measurements of any kind in an area with traffic or other safety risks, another crew member must spot.
- Crew members should avoid standing on runways or taxiways during data collections unless needed.
- Crew members should avoid standing in open traffic lanes present at the airport. If walking along an open stretch of roadway, crew members should walk against the flow.
- As noted in the Data Collection Plan, the team will minimize time on runways by having non-data collection activities, such as data-collection conversations, battery charging, and checking data collection outside of the Runway Safety Area. A representative Runway Safety Area 76.2 meters from the runway centerline and 304.8 m from the ends of the runway is being used, so team will stay outside these areas when not completing a data collection and will keep away 76.2 m horizontally from any moving aircraft.

#### P.4 SMALL UNMANNED AIRCRAFT SYSTEM SAFETY

The pilot-in-command (PIC, Richard Dobson) will brief all participants a day prior to field collections of where the sUAS will be operating, safe places and minimum distances to stand or work while the sUAS is taking off/landing and collecting data, and general safety procedures. Under Part 107, any individual without a remote pilot's certificate may not operate a drone unless being directly supervised by a person with a remote pilot's license. Only certified Part 107 pilots will fly sUASs.

- Remain a safe distance from and do not stand directly below a flying sUAS.
- DO NOT attempt to distract the pilot or designated spotters while the sUASs are being operated unless it is an immediate emergency.
- All sUAS operations MUST have a designated spotter.
- If any low flying aircraft are spotted and heading towards the sUAS flight path, all operations must immediately end until safe passage of the manned aircraft.
- Listen to the pilot-in-command at all times.
- The field team will have a small fire extinguisher on hand at the place of sUAS operation in case of a battery fire.

#### P.5 FIRST AID AND MEDICAL

- First aid kit will be on site with the field crew for all site visits.
- Emergency number is 911.
- Nearest hospital location to study site: Cape Regional Medical Center, Cape May Court House, New Jersey (15.5 km, 17 minutes).
  - 218 N Main St, Cape May Court House, New Jersey 08210.
- MTRI phone number: (734) 913-6870, Lisa Phillips (Office Manager, MTRI safety lead. Any workplace injury must be reported to Ms. Phillips, and appropriate forms must be filled out if medical care is sought due to any workplace injuries.
- ISU phone number: (515)-294-8213, Paul Kremer (Manager Research, CCEE, ISU). Any workplace injury must be reported to Mr. Kremer if medical care is sought due to any workplace injuries.
- APTech. phone number: (217) 398-3977, APTech headquarters is in Urbana, Illinois.

#### P.6 COVID-19 SAFETY GUIDANCE FOR FIELD WORK

- **Notes:** Most states have lifted COVID-19 restrictions. More information on New Jersey COVID-19 guidance is available at: <https://covid19.nj.gov/> .
- ISU's COVID-19 safety Plan
  - The COVID-19 guidelines have been updated for regent institutions in Iowa on May 20, 2021. Mask use continues to be encouraged for those who have not been vaccinated, and optional for those who have been vaccinated.
  - Travelers have been encouraged to adhere to Center for Disease Control (CDC) guidance for domestic travel.

- The team will follow the rules outlined by the Iowa State University Transportation Services while operating the vehicle and properly clean inside the vehicle while returning.
- All details are available at the following web addresses:
  - COVID-19 guideline update for regent institutions in Iowa: <https://www.iowaregents.edu/news/board-news/statement-from-president-mike-richards-lifting-regents-state-of-emergency>
- ISU safety and health policy resources: <https://web.iastate.edu/safety/>
- ISU safety policy on COVID-19: <https://web.iastate.edu/safety/updates/covid19>
  - ISU gathering and events policy: <https://web.iastate.edu/safety/updates/covid19/events-gatherings>
- ISU Civil, Construction, and Environmental Engineering (CCEE) safety resources: <https://www.ccee.iastate.edu/safety/>
- ISU CCEE research and instructional labs and fieldwork safety policies: <https://www.ccee.iastate.edu/files/2019/07/CCEE-Laboratory-Policies-and-Guidelines-CCEE-Safety-and-Health-Committee-and-EHS-Reviewed-and-Approved-2.23.2-3.pdf>
- MTRI's COVID-19 Safety Plan
  - MTRI's COVID-19 safety plans have been as follows, and unvaccinated participants are expected to follow them closely:
    - Field crew will stay at least 6' apart and wear face coverings when within 10' of other people.
    - Field crew travel with hand sanitizer and use it at the beginning and end of the day, and at all breaks.
    - Field equipment will be individually assigned as much as possible (for example, whomever starts with a particular sUAS will use that one throughout the day) and will be disinfected with Lysol®-type wipes when possible.
  - Multiple workers are allowed to travel within the same vehicle when the University's Health and Safety Level is at Level 2.
  - As of 6/9/2021, the University is at Level TWO. (<https://www.mtu.edu/flex/operations/levels/>).
  - Note that there is a cleaning protocol for the MTRI Durango that MUST be followed – laminated copies can be found inside the Durango.
  - Work is to comply with the Michigan Tech COVID-19 Fieldwork protocol and safety checklist found at the locations shown below:
    - COVID-19 Research FAQs: <https://www.mtu.edu/research/covid-19/faqs.html>
    - Current campus health and safety level: <https://www.mtu.edu/flex/operations/levels/>
    - Research Pandemic Checklist: Research Pandemic Checklist - Google Docs

- Now that the University is back at Level 2, travel authorization is obtained through the normal channel of submitting a signed MTRI Travel Authorization Form to the MTRI Co-Directors for their approval, with a cc: to Office Manager/ Facility Security Officer Lisa Phillips. That permission is being obtained for this data collection.
- COVID-19 safety guidelines of Illinois
  - <https://coronavirus.illinois.gov/>

*Note: All website links provided above are accessible during this data collection plan development. However, all websites are not expected to be maintained and updated by the authority in future as COVID-19 situation is expected to be changed.*

APPENDIX Q—PAVEMENT CONDITION INDEX DATA COLLECTION PLAN

Applied Pavement Technology, Inc. Field Data Collection and Safety Plan  
 Custer Airport: January 18–19, 2021  
 Grosse Ile Municipal Airport: January 19–20, 2021

Applied Pavement Technology, Inc. Survey Team	<ul style="list-style-type: none"> <li>• Katie Gauthier, P.E.</li> <li>• Trent Montgomery</li> </ul>
Schedule	<ul style="list-style-type: none"> <li>• January 18, 2021: Drive from Champaign-Urbana, Illinois to Monroe, Michigan</li> <li>• January 18, 2021: Begin data collection at Monroe County Airport</li> <li>• January 19, 2021: Complete data collection at Monroe (if necessary), travel to Grosse Ile Airport, and begin data collection.</li> <li>• January 20, 2021: Complete data collection at Grosse Ile and return to Champaign-Urbana, Illinois (trip may be extended one day more if additional inspection time is needed).</li> </ul>
Airport Contacts	<p>Dan Diesing, Monroe County                  Michael Duker, Grosse Ile</p> <p>Both airports have been contacted, are aware of the schedule and planned activities, and have given permission for the field crew to be onsite to perform the described data collection.</p>
Safety Plan	<ul style="list-style-type: none"> <li>• Inspectors will follow the safety procedures of operating on an active airfield.</li> <li>• ANSI Type II reflective vests will be worn at all times.</li> <li>• Inspectors will work in a group of two.</li> <li>• The vehicles will have a working strobe beacon while on airfields.</li> <li>• All site rules and driving speed limits will be followed.</li> <li>• Crews will monitor UNICOM radio frequencies and use situational awareness to track and react to any aircraft.</li> <li>• The crew will give way to all aircraft movements.</li> <li>• Runway inspection work will be coordinated around aircraft movements.</li> <li>• Inspectors will wear multiple layers of warm clothing.</li> <li>• Inspectors will take breaks to allow them to warm up when needed.</li> <li>• Inspectors will wear proper closed-toed footwear.</li> <li>• Inspectors will remain on paved surfaces when possible.</li> <li>• Inspectors will wear earplugs when aircraft operations are ongoing.</li> </ul>

<p><b>COVID-19 Safety</b></p>	<p>See attached <i>APTech COVID-19 Health and Safety Guidelines and Protocols for Fieldwork</i> document. This has been shared with both airport managers.</p> <p>No meetings are anticipated, but any interactions can occur outside, with all parties wearing masks and maintaining physical distance greater than 6 ft.</p>																																																																									
<p>Operational Plan for Data Collection</p>	<p>The crew is performing a visual pavement condition survey within select branches and sections at each airport. The following sample units (SU) will be inspected:</p> <table border="1"> <thead> <tr> <th colspan="3">Monroe County</th> <th colspan="3">Grosse Ile</th> </tr> <tr> <th>Surface</th> <th>Section</th> <th>Sample Unit</th> <th>Surface</th> <th>Section</th> <th>Sample Unit</th> </tr> </thead> <tbody> <tr> <td rowspan="8">A01MN</td> <td rowspan="8">10</td> <td>1</td> <td rowspan="16">RW1735 GI</td> <td rowspan="8">10</td> <td>03</td> </tr> <tr> <td>8</td> <td>05</td> </tr> <tr> <td>11</td> <td>08</td> </tr> <tr> <td>17</td> <td>12</td> </tr> <tr> <td>21</td> <td>14</td> </tr> <tr> <td>27</td> <td>17</td> </tr> <tr> <td>30</td> <td>20</td> </tr> <tr> <td>35</td> <td>05</td> </tr> <tr> <td rowspan="9">RW321 MN</td> <td rowspan="9">10</td> <td>3</td> <td rowspan="9">20</td> <td>14</td> </tr> <tr> <td>13</td> <td>23</td> </tr> <tr> <td>16</td> <td>31</td> </tr> <tr> <td>23</td> <td>40</td> </tr> <tr> <td>33</td> <td>49</td> </tr> <tr> <td>43</td> <td>58</td> </tr> <tr> <td>53</td> <td>67</td> </tr> <tr> <td>63</td> <td>76</td> </tr> <tr> <td>73</td> <td>85</td> </tr> <tr> <td rowspan="6">TWAMN</td> <td rowspan="6">10</td> <td>7</td> <td rowspan="6"></td> <td>94</td> </tr> <tr> <td>16</td> <td>103</td> </tr> <tr> <td>23</td> <td>112</td> </tr> <tr> <td>25</td> <td></td> </tr> <tr> <td>29</td> <td></td> </tr> <tr> <td>35</td> <td></td> </tr> <tr> <td></td> <td></td> <td>41</td> <td></td> <td></td> </tr> </tbody> </table> <p>Each crew member will use a handheld tablet computer equipped with a GPS unit to locate and map distresses in each SU. The crew will also be taking photographs to document general conditions and specific distresses</p>	Monroe County			Grosse Ile			Surface	Section	Sample Unit	Surface	Section	Sample Unit	A01MN	10	1	RW1735 GI	10	03	8	05	11	08	17	12	21	14	27	17	30	20	35	05	RW321 MN	10	3	20	14	13	23	16	31	23	40	33	49	43	58	53	67	63	76	73	85	TWAMN	10	7		94	16	103	23	112	25		29		35				41		
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## APPENDIX R—AIRFIELD PAVEMENT DISTRESSES

### R.1 INTRODUCTION

Table R-1 is the key to airport distress types for both asphalt and concrete runways, from the Concrete Surfaced Airfields PAVER™ Distress Identification Manual (USACE, 2009a) and Asphalt Surfaced Airfields PAVER™ Distress Identification Manual (USACE, 2009b).

Table R-1. Airfield Pavement Distresses

Asphalt Surface		Concrete Surface	
Distress type	Distress ID	Distress type	Distress ID
Alligator or fatigue cracking	41	Blowup	61
Bleeding	42	Corner break	62
Block cracking	43	Cracks	63
Corrugation	44	Durability (“D”) cracking	64
Depression	45	Joint seal damage	65
Jet blast erosion	46	Patching, small	66
Joint reflection cracking	47	Patching, large	67
Long & trans cracking	48	Popouts	68
Oil spillage	49	Pumping	69
Patching and utility cut patch	50	Scaling	70
Polished aggregate	51	Settlement or faulting	71
Raveling	52	Shattered slab	72
Rutting	53	Shrinkage cracks	73
Shoving	54	Spalling (joint)	74
Slippage cracking	55	Spalling (corner)	75
Swell	56	Alkali silica reaction	76
Weathering	57		

### R.2 REFERENCES

United States Army Corps of Engineers (USACE). (2009a, June). *Concrete surfaced airfields PAVER™ distress identification manual*. U.S. Army Engineering Research and Development Center- Construction Engineering Research Laboratory. [https://www.faa.gov/documentLibrary/media/Advisory\\_Circular/Concrete-Surfaced-Airfields-Distress-Manual.pdf](https://www.faa.gov/documentLibrary/media/Advisory_Circular/Concrete-Surfaced-Airfields-Distress-Manual.pdf)

USACE. (2009b, June). *Asphalt surfaced airfields PAVER™ distress identification manual*. U.S. Army Engineering Research and Development Center- Construction Engineering Research Laboratory. [https://www.faa.gov/documentLibrary/media/Advisory\\_Circular/Asphalt-Surfaced-Airfields-Distress-Manual.pdf](https://www.faa.gov/documentLibrary/media/Advisory_Circular/Asphalt-Surfaced-Airfields-Distress-Manual.pdf)